A Report to the U. S. Army Corps of Engineers

on

The Environmental Consequences of Dredge Spoil Disposal in Central Long Island Sound:

I. The New Haven Spoil Ground and New Haven Harbor

by

Robert B. Gordon

Donald C. Rhoads

Karl K. Turekian

Department of Geology and Geophysics

Yale University

New Haven, Connecticut 06520

October 1972

TABLE OF CONTENTS

Introduction

Geophysical Studies 1

Benthic Biology and Habitat Documentation 17

Geochemistry of Long Island Sound and
New Haven Harbor Sediments and Organisms 25

Conclusions 29

Recommendations 38

Acknowledgements

References

Plates

Appendix

INTRODUCTION

Ports on Long Island Sound are naturally shallow. Because shipping channels in these ports are subject to rapid siltation, periodic dredging is required to keep them open to safe navigation. All of the larger harbors on Long Island Sound are used by neighboring municipalities for the disposal of sewage and industrial wastes. Consequently, sediment dredged from these harbors often contains significant amounts of contaminant materials and its disposal must be done with great care if adverse environmental consequences are to be avoided.

This report presents the results of a three month study of the environmental consequences of dredging in New Haven Harbor with disposal of the resultant dredge spoil in Long Island Sound on the designated dumping ground south of New Haven. The investigation is a part of a larger, interdisciplinary study at Yale of Central Long Island Sound as a biological, chemical and physical system. The study reported here was made during the period July-September 1972 and was supported by the New England Division of the U. S. Army Corps of Engineers. At the time the study started it was expected that maintenance dredging operations in New Haven Harbor would commence on 15 August 1972. Consequently, the first objective was to obtain during the summer months as much "pre-dump" information as possible about the spoil ground. Emphasis was placed on field work to establish a data base against which subsequent changes could be compared. Because of this emphasis, some specimens taken have yet to be studied in detail and some data recorded during the summer are still being reduced. Further information will be developed in subsequent months, but this report does contain all of the most important results of the study.

GEOPHYSICAL STUDIES

The primary aim of the geophysical part of the study program is to determine whether or not dredge spoil can be deposited on the bottom at the designated dump point without unacceptably great dispersion, and whether, once deposited, this material will stay in place. Tidal streams are strong in Central Long Island Sound (LIS) and are thought to be responsible for rapid transport of natural sediments in the area. There are no useful data available on water velocities near the bottom of LIS. Consequently, determination of the tidal and non-tidal water flow in Central LIS is one objective of the research. Tidal streams in the Sound move sand over the bottom as bed load and silt in resuspension. Essentially no natural sand occurs near the dump site but tidal resuspension of bottom silt is anticipated. The extent of the resuspension, a source of natural turbidity in LIS water, is determined at stations at and around the designated dump area. The degree to which dumped material penetrates and intermixes with existing bottom sediments will influence its subsequent stability in the presence of tidal streams and storm events. To permit evaluation of this interaction, measurement of bottom mechanical properties are made. To some extent the form and distribution of dumped spoil can be determined by precision fathometer surveys. Base lines establishing the present bottom configuration have been run for comparison with future surveys. A final aspect of this part of the work is a survey of the naturally occurring turbidity in New Haven Harbor.

Tidal Streams and Heights. Three methods of observation have been used in the study of tidal streams in Central LIS.

i. Recording Current Meters. Four Braincon type 381 histogram current meters have been in operation in the study area since late June. The type 381 meter records the direction and amount of water flow in successive 20 minute intervals for up to 50 days. Each meter is bottom-moored to a steel weight secured to a Danforth anchor and is set (in most cases) to record the current at a height of 180 cm above the bottom. (This height is within the zone of active bottom sediment transport but is sufficiently high to discourage interference with the meter rotors by migratory bottom animals.) The meter location is fixed by microwave range measurements from Stratford Point and the Old Tower on Lighthouse Point or by horizontal sextant angles and is identified by an acoustic beacon and a marker buoy while the meter is on station. The meters are set and recovered by divers; thus, their correct operation is assured by visual inspection while on station.

ii. Deep Drifter. A drogue set for a depth of 15 meters is attached to a float fitted with a radar reflector on a pole. This was released at the spoil ground and tracked from the Manamet on several occasions.

iii. Velocity Gradient. A number of measurements of the velocity gradient from top to bottom of the water column were made from a moored boat with a Price current meter. The procedure is to moor the boat at bow and stern and support the meter on a taut wire run to a weight set on the bottom. Electrical pulses generated by rotation of the meter bucket wheel are indicated on a strip chart recorder; current speed is found by counting the pulses recorded over a fixed time interval and using the manufacturer's calibration data for the meter.

During the study period an automatic, recording tide gauge has been kept in operation at the Yale Marine Station, Leetes Island.

A summary of the operations of the Braincon current meters is shown in Table 1. Fig. 1 is an index map of the current meter stations. In the first set of observations an array of three meters set for heights of 51, 183, and 500 cm was operated at the dump site (actually the "A" buoy position established by the Corps in May 1972). In order to cover as many stations as possible with the four meters available, subsequent moorings were made with a single meter each at a height of 180 cm.

The record obtained 180 cm above the bottom at the New Haven spoil ground has been studied in most detail so far. The tidal stream here is rotary but with the strongest flow in the E-W direction. Fig. 2 gives an example of the components of the current velocity measured at this site at 20 minute intervals. From Fig. 3, a plot of successive velocity vectors (for 20 minute intervals), it is evident that there is a non-tidal flow at this station which is for the most part in a northwesterly direction at a rate of about 1-2 cm/sec. The shift of the second cycle toward the south was probably due to the strong wind that was blowing toward the SW, with a maximum speed twice that observed during the succeeding days.

In order to make predictions of tidal streams over the spoil ground and to accurately separate the tidal and non-tidal flow, a harmonic analysis of 10 days of velocity data from this site was made. Because the flow is rotary, it is necessary to resolve each velocity vector into N-S and E-W components and to analyze each resulting velocity curve separately. The method of analysis used is that described in the <u>Admiralty Tidal Handbook No. 3</u>. For the four tidal stream constituents, M_2, S_2, K_1, and O_1, the analysis yields the harmonic constants g (the phase lag of the constituent at a given

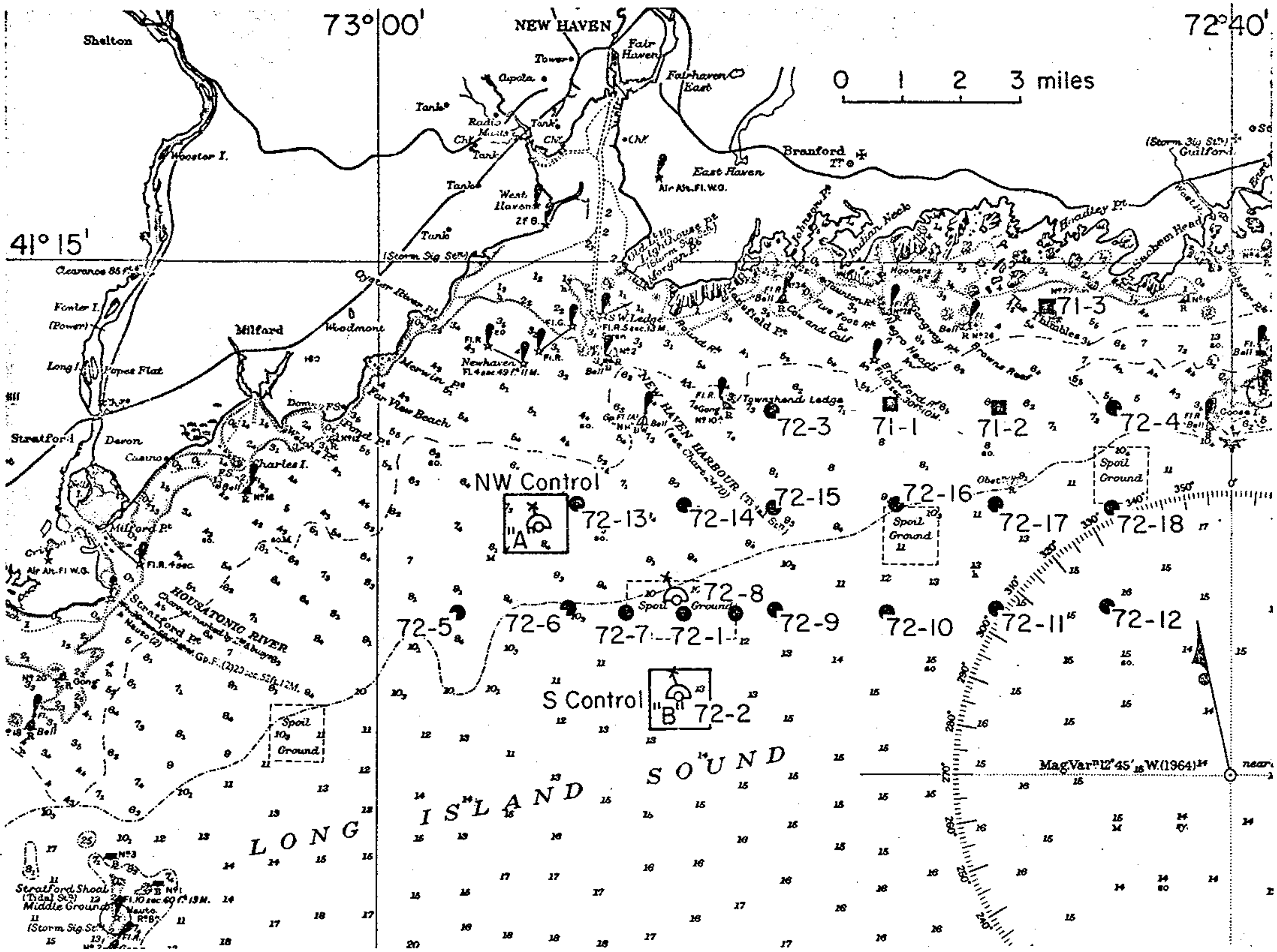
Table I

Current Meter Program, Summer 1972

(through 30 September)

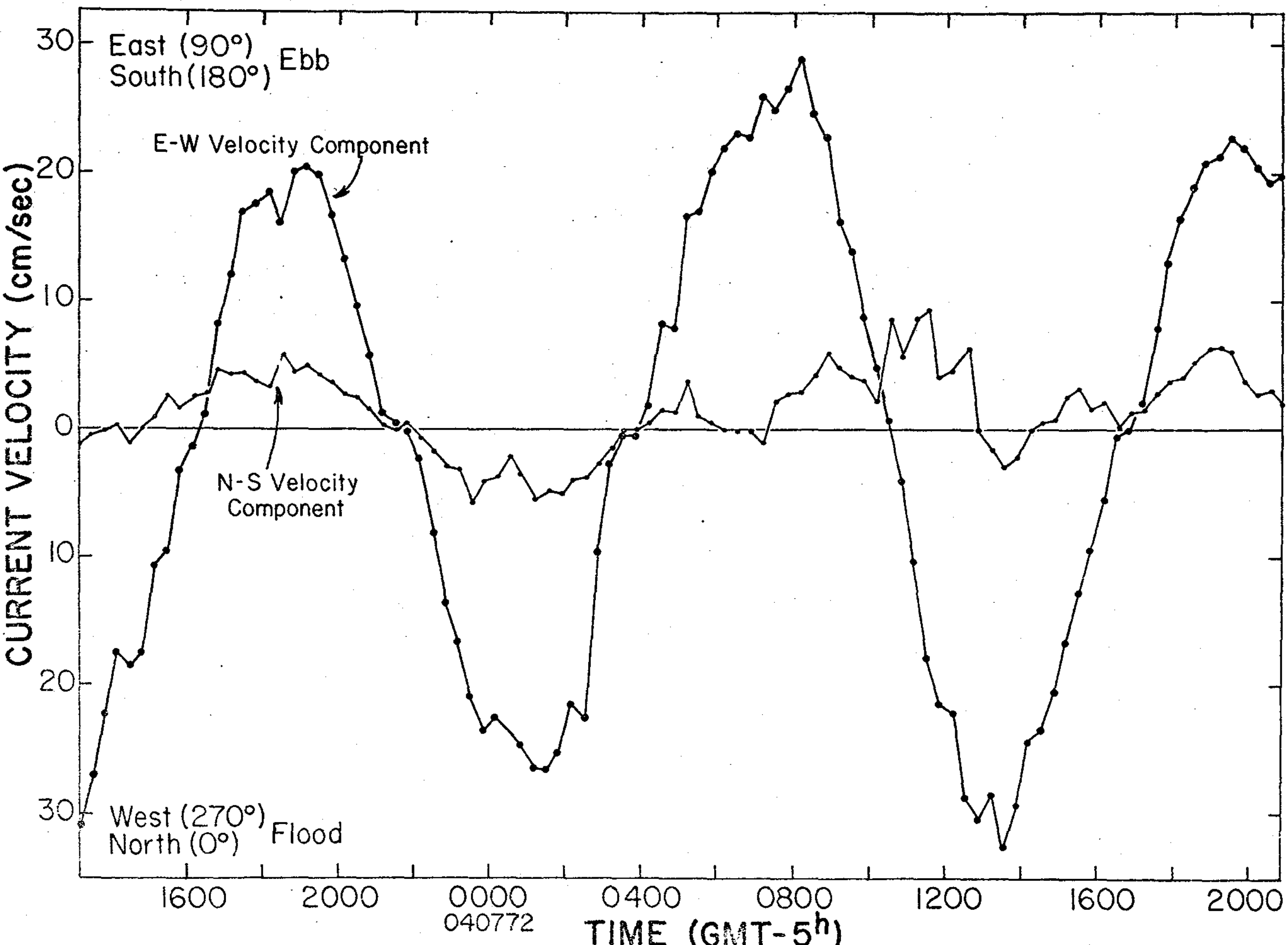
Dates	Location	Location Description	Z	Meter #	Results/Remarks
290672- 120772	41°08'.75N 72°52'.9 W	NH Spoil Ground	500 cm 183 51	105 106- 107	Timer stopped after ~7 days Data used for harmonic analysis Mechanism failed
120772- 020872	41°07'.4 72°52'.9	South Con- trol Site	50	108	Floatation failed, partial record obtained
280772- 200872	41°09'.0 72°51'.6	Station 72-8	180	106	Good record
010872- 180872	41°08'.9 72°55'.6	Station 72-6	180	107	Good record
230872- 120972	41°10'.9 72°53'.1	Station 72-14	180	106	Meter recovered, film being processed
200872- 120972	41°10'.9 72°48'.1	Station 72-16	180	107	Meter recovered, film being processed
200872- 040972	41°08'.9 72°48'.0	Station 72-10	180	108	Record still in meter.
120972- 031072	41°10'.4 72°56'.3	NW Control Site	180	106	Meter recovered, film being processed
120972- 280972	41°10'.8 72°45'.4	Station 72-17	180	107	Meter recovered, film being processed
080972- --	41°10'.8 72°42'.6	Station 72-18	180	108	Still on station
160972- 041072	41°09'.1 72°58'.2	Station 72-5	180	105	Meter recovered, film being processed

Figure 1. Index map of north central Long Island Sound showing the location of the New Haven spoil ground (marked by a lighted buoy) and the control sites. Current meter stations are shown by numbers. Bottom current data for stations designated "71" are available from earlier studies.



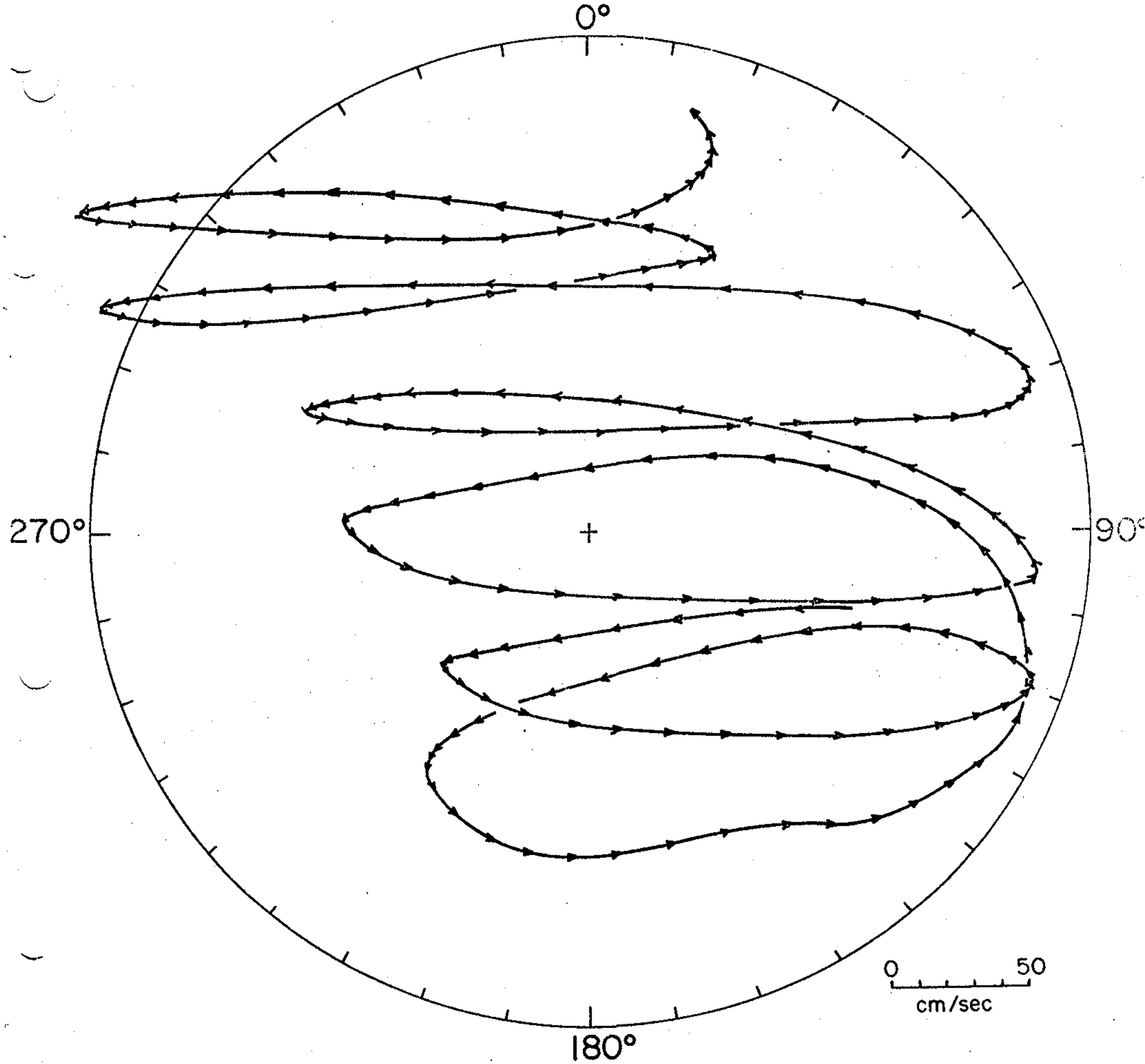
73°00'
72°40'
41°15'
NEW HAVEN
0 1 2 3 miles
Shelton
Milford
Stratford
Devon
Woodmont
Branford
East Haven
Guilford
Fair Haven
NW Control
"A"
S Control
"B"
72-1
72-2
72-3
72-4
72-5
72-6
72-7
72-8
72-9
72-10
72-11
72-12
72-13
72-14
72-15
72-16
72-17
72-18
71-1
71-2
71-3
NEW HAVEN HARBOUR
HOUSATONIC RIVER
Spoil Ground
LONG ISLAND SOUND
Mag.Var.n 12°45' W. (1964)
Stratford Shoal
Middle Ground
Charles I.
Stratford Pt
Milford Pt
Townshend Ledge
Thimbles
Sachem Head
Indian Neck

Figure 2. Components of the current velocity measured at 20 minute intervals at the New Haven spoil site (41°08'.75N, 72°52'.90W). Magnetic north is 0°, Z = 183 cm.



East (90°)
South (180°) Ebb
West (270°)
North (0°) Flood
E-W Velocity Component
N-S Velocity Component
CURRENT VELOCITY (cm/sec)
30
20
10
0
10
20
30
1600
2000
0000
040772
0400
0800
1200
1600
2000
TIME (GMT-5h)

Figure 3. Successive velocity vectors (for 20 minute intervals) observed at the New Haven spoil ground over a period of about three days. The record starts at 0916 GMT-5 on 29 June 1972. True north is 0°.



R. Lowen 9/72

place behind the corresponding tide-raising force at Greenwich) and H (the flow rate at a given place when the nodal correction factor, which arises because of the rotation of the plane of the moon's orbit, is unity). The constituents M_2 and S_2 are the principal semi-diurnal constituents, and O_1 and K_1 are the principal diurnal constituents. Once g and H are determined for both components of the velocity, the tidal stream flow can be specified at a particular place for all times. The results of the analysis for the E-W direction (magnetic), the direction of maximum rates, are given in Table 2. As indicated by observations in the Sound, the values of g for the tidal stream constituents lag by about 80-90° the values of g determined for the tide heights in a nearby area. The net flow for this flow component was 1.7 cm/sec to the west. Thus the representation of tidal action in Central LIS as a simple standing oscillation of the water with a node near the Race is a good first approximation.

If the velocity field were uniform over the area surrounding the spoil ground, the progressive vector diagram in Fig. 3 would also represent the actual water displacement in the area. A check for any large irregularity in the velocity field can be made by comparing the path followed by the deep drifter with that predicted on the basis of the current meter data. The drifter was released and tracked from the Manamet on these occasions:

18 July, 1030 to 1536 Q, on spoil ground

19 July, 1011 to 1550 Q, on S control site

25 July, 0932 to 1504 Q, on spoil ground.

The drifter tracks are shown in Fig. 4. As can be seen from the figure, the drifter paths are generally consistent with the vector diagram. Moreover,

Table 2

Harmonic Constants for E-W Component of Tidal Stream,

New Haven Spoil Ground

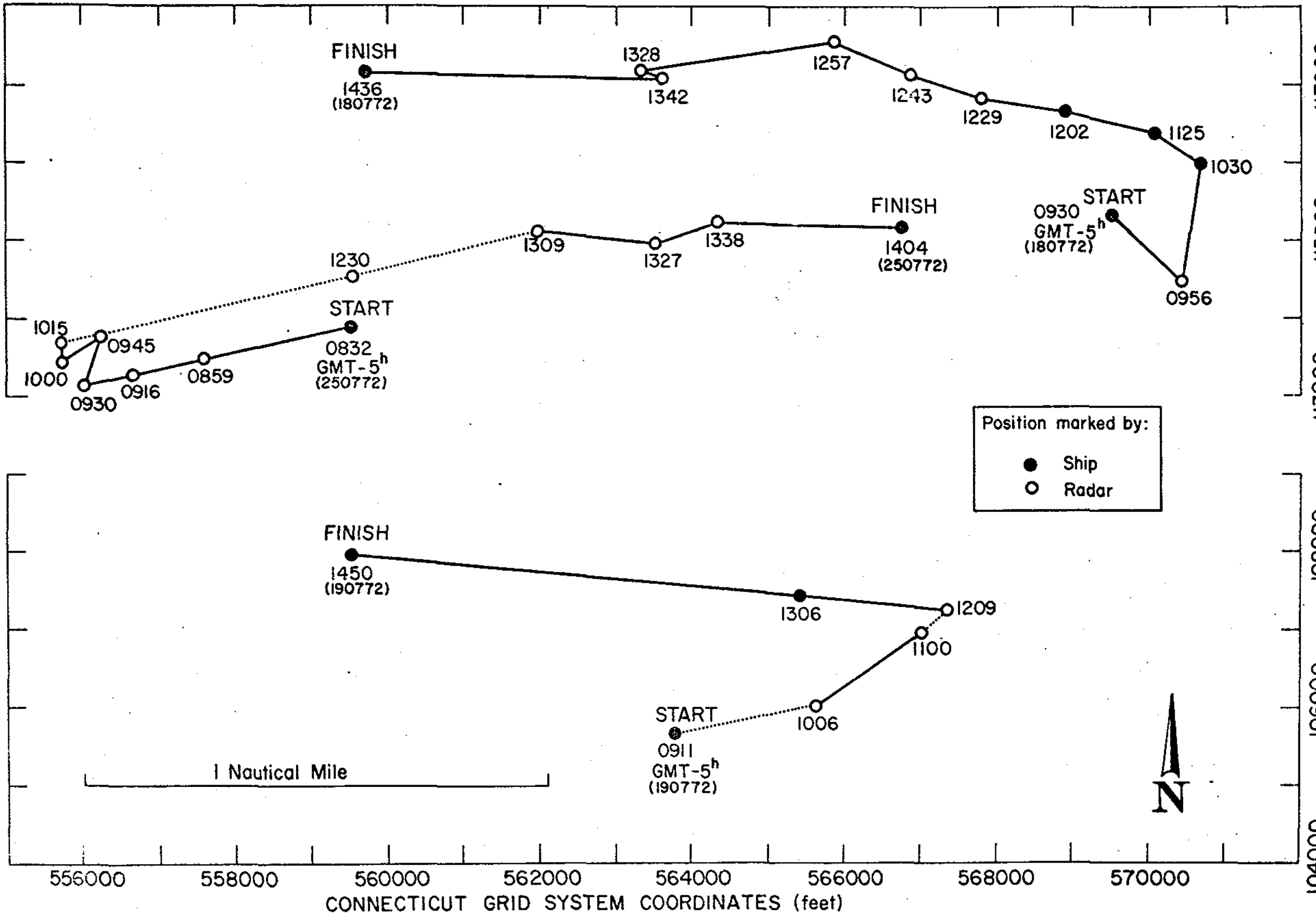
	M_2	S_2	K_1	O_1
g (degrees)	38	49	201	244
H (cm/sec)	22.4	4.0	1.2	0.7

flow speeds calculated from these tracks are in agreement with those calculated from the current meter data. It is concluded, therefore, that there are no large-scale irregularities in the velocity field in this region.

The shear stress responsible for sediment erosion is determined by the magnitude of the velocity gradient at the bottom. An approximate bottom stress can be inferred if it is assumed that the Kàrman-Prandtl, or logarithmic, velocity law holds and the approximate bottom roughness is used. Evidence that this law does hold in a tidal stream when the sea bed is free of large scale undulations has been presented by Dyer (1970). Six gradient measurements were made, as described in Table 3 to test the logarithmic law for Central LIS. The results obtained at the New Haven spoil ground, shown in Fig. 5, indicate that there is not a logarithmic velocity gradient throughout the water column at this station. On the flood, the surface water is substantially retarded and maximum velocity occurs well down in the water column. This retardation is not present on the ebb. The simplest interpretation of these results is that in August there is a significant estuarine circulation at the dump site with, presumably, fresher surface water moving eastward and saline bottom water, westward. The latter may be identified with the net westward drift detected by the current meters on this station. Salinity and temperature measurements made at the dump site at the same time as the velocity gradient determination are shown in Fig. 6; they confirm the presence of the two-layer structure.

For comparison, the velocity gradient of the flood current at the site of the benthic recolonization experiment being made by J. B. Fisher and P. McCall off Leetes Island was measured. At this site, designated "JBF"

Figure 4. Deep drifter tracks recorded on three occasions in the vicinity of the New Haven spoil ground. Dark circles indicate positions fixed with the ship alongside the drifter and are precise to within a few meters; the remaining points were fixed by radar range and bearing and are not as accurate. Times are GMT-5^h.



FINISH
1436
(180772)
1328
1342
1257
1243
1229
1202
1125
1030
START
0930
GMT-5h
(180772)
0956
FINISH
1404
(250772)
1309
1327
1338
1230
START
0832
GMT-5h
(250772)
1015
0945
1000
0930
0916
0859
Position marked by:
Ship
Radar
FINISH
1450
(190772)
1306
1209
1100
1006
START
0911
GMT-5h
(190772)
1 Nautical Mile
N
556000
558000
560000
562000
564000
566000
568000
570000
CONNECTICUT GRID SYSTEM COORDINATES (feet)
117000
115000
113000
108000
106000
104000

Table 3

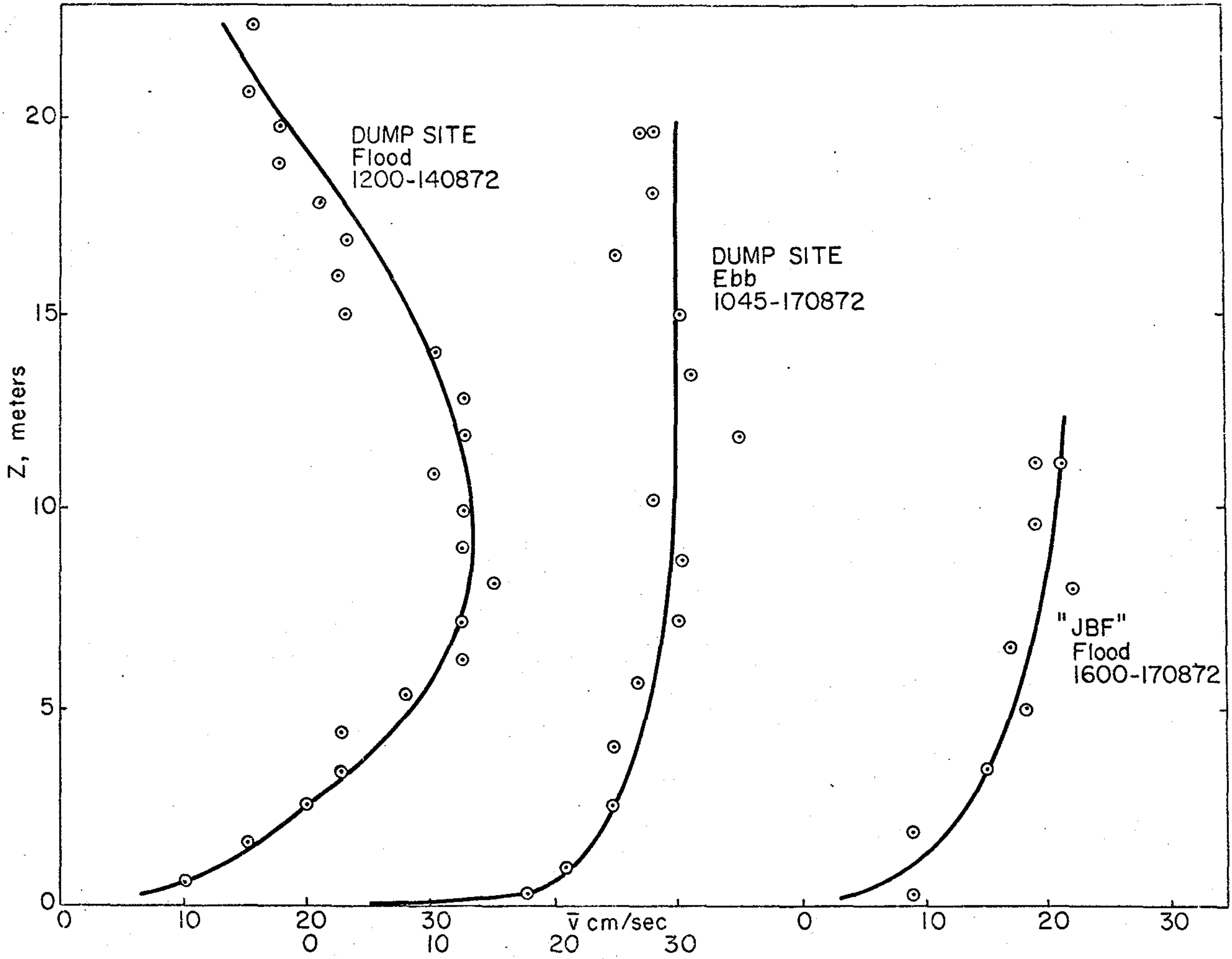
Velocity Gradient Measurements--Price Current Meter--Summer 1972

Date	Time	Tide	Tide Range	Station	L	λ	Other Data
140872	1130 Q	LW + 2^h30^m	Neap	Dump site	41°08'.8	72°52'.9	--
	1200	LW + 3^h00^m		Dump site	41°08'.8	72°52'.9	--
	1625	HW + 1^h15^m		S of JBF	41°11'.4	72°43'.6	%t
160872	1400	LW + 3^h30^m	Neap	Dump site	41°08'.8	72°52'.9	T,%t
170872	1045	LW - 1^h	Neap	Dump site	41°08'.8	72°52'.9	S,T,%t
	1600	HW - 1^h30^m		JBF	41°13'.3	72°43'.8	S,T,%t

Explanation: Station "JBF" is the location of a benthic recolonization study being carried on south of Leetes Island.

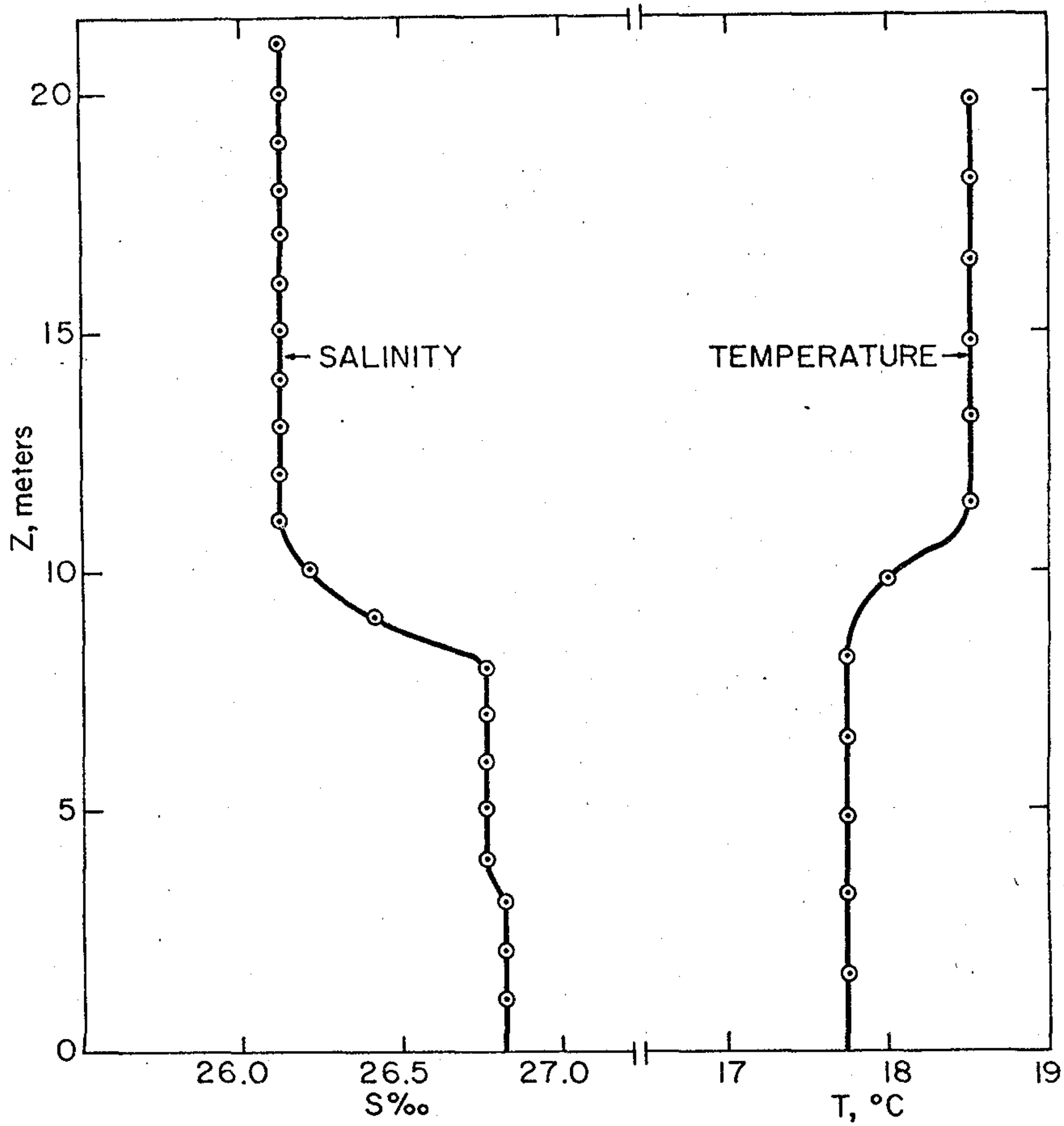
The "Other Data" are salinity, S; temperature, T; and optical transmittance, %t, gradients,

Figure 5. Velocity gradient measurements at two stations in Central LIS. Curves are identified by time and date, see Table 3. Distance measured upwards from the bottom is designated as "Z." The curve for station "JBF" is constructed on the logarithmic velocity law.



DUMP SITE
Flood
1200-140872
DUMP SITE
Ebb
1045-170872
"JBF"
Flood
1600-170872
Z, meters
$\bar{v}$ cm/sec
0
5
10
15
20
0
10
20
30
0
10
20
30
0
10
20
30

Figure 6. Temperature and salinity gradient measurements made on 170872 at the New Haven spoil ground. They confirm the presence of a well developed pycnocline at Z = 10 meters.



RLowen 10/20/72

tidal mixing is very strong and little or no salinity or temperature gradient is detected. A normal, logarithmic velocity curve is found, Fig. 6.

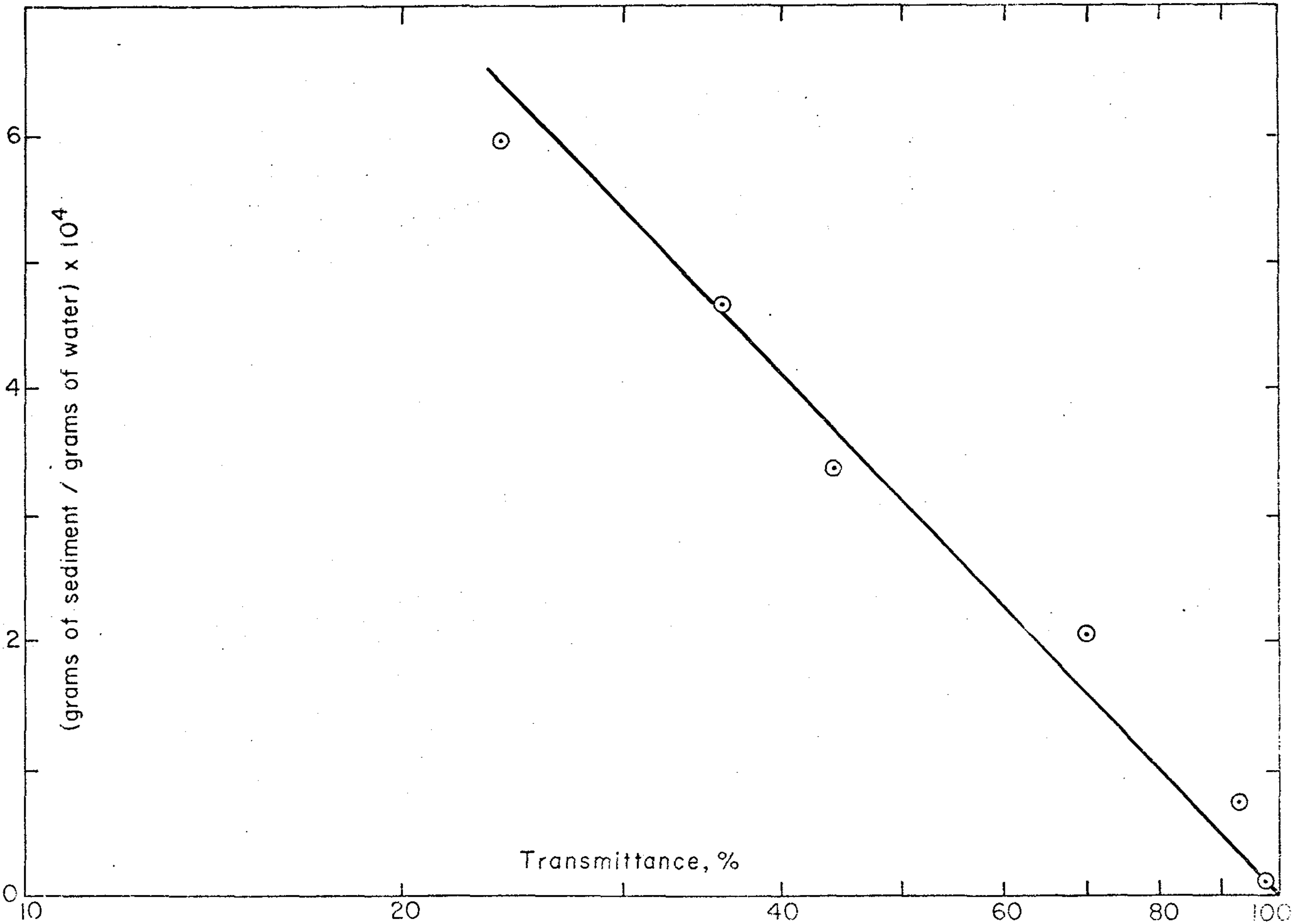
Turbidity and Suspended Sediment Transport. Turbidity is of direct concern because it controls the amount of light penetrating the water column; light is essential to the growth of phytoplankton and seaweeds. Indirect effects are perhaps more important. High turbidity due to silt in suspension makes water unattractive for recreational purposes, may clog the gills of filter feeding animals, and, upon settling, may adversely affect the growth of commercially important shellfish. Because there is no naturally occurring sand in the vicinity of the dump site, suspension of silt is the major mechanism of transport of bottom material. Tidal streams and wave action are anticipated to be the principal natural causes of this suspension. At the time this study began only very limited data on turbidity, and no data on sediment suspension, were available for Central LIS. The objectives of the study of turbidity are to determine the amount and distribution of suspended sediment in the Central Sound and in New Haven Harbor. Because turbidity conditions are highly variable both in space and time, an extensive set of observations is required to meet this objective.

All of the turbidity observations have been made with an optical transmissometer built in our laboratory. The transmittance of white light through a 10 cm column of water is measured and expressed as percent (%t). Simultaneously, water pressure (for depth) and temperature are indicated by the instrument. Temperature and transmittance profiles are recorded automatically on an X-Y plotter while the transmissometer is lowered to the bottom. Alternatively, the transmissometer may be towed at speeds up to 8 knots so that a continuous record of turbidity along the ship's track can be recorded. This technique has been used to study turbidity gradients near the shore and in New Haven Harbor. More sophisticated equipment for studying turbidity is available, but the transmissometer has proved to be rapid and reliable in operation and permits the acquisition of the relatively large amounts of survey data required at this stage of the research. More detailed study of the nature of the suspended sediment should be made in the future.

This study is primarily concerned with turbidity due to suspended sediment. Theory indicates that in dilute suspensions the decrease in the logarithm of the optical transmittance is directly proportional to the sediment concentration. A calibration of the transmissometer was made by resuspending in water weighed quantities of dried sediment taken from the bottom in the study area. The results in Fig. 7 show that the expected linear relationship is found; this is used in subsequent calculations of sediment concentration.

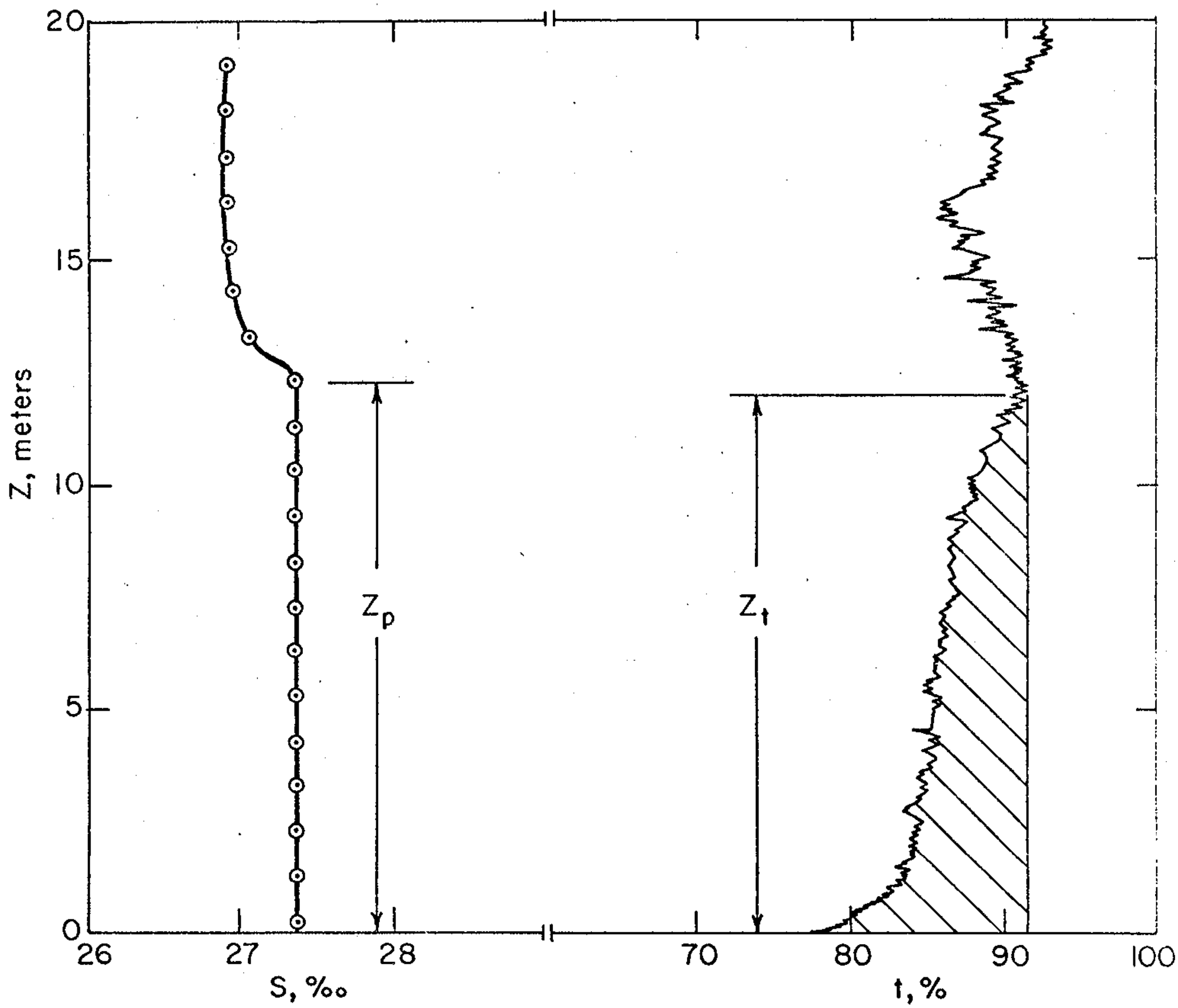
Fig. 8 shows a direct tracing of a recorded transmissometer profile. This is a typical result and will serve to illustrate the procedure used in the interpretation of the transmittance data. Turbidity in LIS water arises from a number of causes--plankton, plant fragments, substances dissolved in the water, and suspended sediment. Laboratory analysis of water samples would be required to identify each of these, but is not practical for extensive monitoring. A measure of the amount of suspended sediment present in the water column can be determined from the shaded area shown in Fig. 8. The concentration of suspended sediment must decrease upwards; the exact form of the decrease depends on the ratio, u/v_*, of settling velocity to friction

Figure 7. Calibration data for the optical transmissometer. Weighed quantities of dried sediment from the bottom in the study area is resuspended in sea water and the resulting transmittance measured.



(grams of sediment / grams of water) x 10^4
6
4
2
0
10
20
40
60
80
100
Transmittance, %

Figure 8. Salinity and transmittance profiles recorded at the New Haven dump site at 1425 Q on 080972. The vertical distance Z is measured upwards from the bottom; the transmittance curve is traced directly from the X-Y recorder chart. Temperature was isothermal to within 0.2° so the height of the pycnocline, Z_p, depends only on salinity. The construction used to determine the turbidity due to resuspended sediment is illustrated. The height to which resuspended sediment penetrates the water column is Z_t.



L. Loomis 10/19/72

velocity. *Only for extremely fine particles, or for very strong turbulence,* is there an approach to uniform mixing from top to bottom. Examination of over a hundred turbidity profiles from Central LIS shows that resuspended bottom sediment always appears with a marked concentration gradient. The resuspended turbidity reaches to the top of the water column only where tidal streams are very strong or in shallow water exposed to wave action (this is seen occasionally at stations well to the east of the dump site). The decrease in transmittance near the top of the water column shown in Fig. 8 is therefore identified with some other source of turbidity (diver observations suggest that it is due to large fragments of organic matter; Riley (1956) reports that only about 30% of the turbidity in LIS water is due to animals and plants), and the height to which resuspended sediment reaches, Z_t, is found by the construction shown. There exists the possibility that Z_t may be drawn too low because of obscuration of sediment-induced turbidity by other materials near the surface. In most cases, however, the shape of the transmittance profile indicates this is not the case. Further evidence is provided by the fact that during the summer months a well-defined pycnocline due to fresher, surface water is present at height Z_p in Central LIS, as illustrated in Fig. 8. (The temperature difference between the upper and lower water layers is very small.) The pycnocline is a barrier to the upwards spread of sediment suspended from the bottom. It is observed that $Z_t \leq Z_p$ in essentially all cases, indicating that all the resuspended sediment has been identified by the construction shown in Fig. 8.

The amount of suspended sediment in the water column is calculated from the shaded area in Fig. 8 and is expressed as ∂, the number of milligrams of suspended sediment per square centimeter of bottom.

An extensive set of turbidity profile observations has been made at the dump site, the south and northwest control sites, and a series of stations surrounding the dump area. At many of these stations salinity and temperature profiles were measured in order to determine Z_p. The observations are all listed in Table 4, with the results summarized in terms of Z_t, Z_p, and $\mathscr{S}$. The observations consist of profiles made at the dump and control sites as frequently as circumstances would permit, several series of observations made to map out the turbidity distribution between the dump site and the surrounding shoreline, and data taken along the ten fathom curve to find the effect of bottom character on resuspension. The results show that resuspended sediment is present in amounts ranging from 0.5 to 70 mgm/cm^2 throughout the north central LIS area. The practical significance of 70 mgm/cm^2 of suspended sediment is illustrated by the fact that it corresponds to a layer of about 0.5 mm thickness removed from the bottom.

Inspection of Table 4 shows that the amount of suspended sediment at any one station is highly variable. It had been anticipated that resuspension would depend on the actual tidal velocity at the time of measurement, on sea state, and on the activity of benthic animals. To separate and identify the importance of each of these factors would require a series of observations at a number of stations over a considerable period of time. A start has been made at obtaining the required data. The total amount of resuspended sediment in the water column at the dump site and at the south control site during the study period is shown in Fig. 9; the state of the tide at the time of each observation is listed in Table 4. Inspection of the table quickly shows that there is no correlation between $\mathscr{S}$ and the tide height and, hence,

Table 4

Suspended Sediment Data from Turbidity Profiles, Summer 1972

Date	Time Q	L N	λ W	Tide	Observed	Z_o m	Z_t m	Z_p m	δ mgm/cm^2	Location/Remarks
030772	1200	41°08'.8	72°52'.9	LW + 1^h40^m	t	21	11	--	14	Dump site ("A")
070772	1530	41°08'.8	72°52'.9	LW + 1^h30^m	t	21	3	--	4.5	Dump site ("A")
	1620	41°07'.4	72°52'.9	LW + 2^h20^m	t	24	12	--	53	South Control site ("B")
110772	1230	41°07'.4	72°52'.9	HW + 0^h40^m	t	26	10.5	--	35	South Control site ("B")
	1300	41°08'.8	72°52'.9	HW + 1^h10^m	t	23	8.5	--	17	Dump site ("A")
120772	1020	41°08'.8	72°52'.9	LW + 4^h20^m	t	21	14.2	--	43	Dump ("A")
	1030	41°07'.4	72°52'.9	LW + 4^h30^m	t	24	16.2	--	69	S. Control ("B")
	1600	41°14'.3	72°43'.6	HW + 3^h15^m	t	12.2	10.3	--	28	S. of Goose Rock
	1615	41°13'.3	72°43'.8	HW + 3^h30^m	t	13.7	11.8	--	38	JBF buoy
	1630	41°11'.5	72°43'.8	HW + 3^h45^m	t	18.0	13.5	--	43	S. of JBF at 10 fathoms
170772	1530	41°10'.8	72°52'.9	HW - 1^h00^m	S	15		10		Station 72-14
180772	1122	41°07'.4	72°52'.7	LW + 0^h30^m	S	24		19		0.3 mi. W. of buoy "B"

Table 4, page 2

Date	Time	L	λ	Tide	Observed	Z_o	Z_t	Z_p	$\mathcal{S}$	Location/Remarks
	Q	N	W			m	m	m	mgm/cm^2	
030872	1120	41°08'.8	72°52'.9	LW	T,t	21.0	11.3	--	12	Dump ("A") $T_b = 17°C$
	1142	41°08'.9	72°51'.6	LW	T,t	21.3	13.4	--	15	Station 72-8 $T_b = 17°C$
040872	1440	41°13'.7	72°46'.8	LW + 1^h50^m	t	13.4	6.1	--	3.9	Near Brown's Reef
	1500	41°13'.3	72°48'.7	LW + 2^h10^m	t	9.7	7.2		3.2	Near Branford Reef
	1510	41°12'.9	72°50'.6	LW + 2^h20^m	t	14.0	7.5		13.5	E. of Towshend Ledge
	1520	41°12'.7	72°52'.6	LW + 2^h30^m	t	14.9	8.7		13	W. of Towshend Ledge
	1535	41°11'.7	72°55'.0	LW + 2^h45^m	t	10.6	2.6		1.9	W. of N. H. sea buoy
	1550	41°08'.9	72°55'.6	LW + 3^h00^m	t	19.8	10.7		14.3	Station 72-6
	1600	41°08'.8	72°52'.9	LW + 3^h10^m	t	22.0	13.6		15.0	Dump ("A")
	1610	41°08'.9	72°51'.6	LW + 3^h20^m	t	21.9	12.0		8.8	Station 72-8
	1625	41°08'.9	72°48'.0	LW + 3^h35^m	t	25.9	11.4		13	Station 72-10
	1645	41°10'.8	72°48'.0	LW + 3^h50^m	t	18.3	6.5		9.1	Station 72-16
080872	0945	41°13'.3	72°43'.8	HW - 0^h30^m	t	13.7	13.7	--	--	JBF (Whitecaps)
	1045	41°08'.8	72°52'.9	HW + 0^h30^m	t	23	15.0	--	29	Dump ("A")

Table 4, page 3

Date	Time Q	L N	λ W	Tide	Observed	Z_o m	Z_t m	Z_p m	$\mathcal{S}$ mgm/cm^2	Location/Remarks
090872	1050	41°08'.8	72°52'.9	HW - 0^h40^m	t	23	15	--	27	Dump ("A")
110872	1450	41°11'.9	72°40'.8	HW + 1^h50^m	t	26	13	--	15	Near Goose Island
	1500	41°11'.8	72°41'.6	HW + 2^h00^m	t	24	11	--	10	W x S of above on 10 fathom curve
	1515	41°11'.7	72°42'.1	HW + 2^h15^m	t	19.6	17	--	18	W x S of above on 10 fathom curve
	1530	41°11'.5	72°44'.5	HW + 2^h30^m	t	19.4	17		15	W x S of above on 10 fathom curve
	1545	41°09'.8	72°48'.5	HW + 2^h45^m	t	19	13		19	WSW of above
	1605	41°09'.2	72°51'.0	HW + 3^h05^m	t	21	13		13	W x S of above
	1635	41°08'.8	72°57'.0	HW + 3^h35^m	t	18	6.3		9	W of dump ground
	1650	41°09'.0	72°58'.6	HW + 3^h50^m	t	15	8.8		18	W x N of above
140872	1625	41°11'.4	72°43'.6	HW + 1^h30^m	t,v	18.3	13.5	--	31	S. of JBF(v grad. meas.)
160872	1400	41°08'.8	72°52'.9	LW + 3^h30^m	T,t,v	19.8	2	--	1	Dump ("A")(v grad. meas.)
170872	1045	41°08'.8	72°52'.9	LW - 1^h00^m	S,T,t,v	19.7	8	8	5.4	Dump ("A")(v grad. meas.)
	1507	41°13'.3	72°43'.8	HW - 2^h00^m	S,T,t,v	12.5	7	8	5.1	JBF(v grad. meas.)

Table 4, page 4

Date	Time Q	L N	λ W	Tide	Observed	Z_o m	Z_t m	Z_p m	mgm/cm^2	Location/Remarks
210872	1550	41°14'.3	72°43'.6	LW + 1^h00^m	S--	11	--	none	--	Near Goose Rock $27.1<S<27.4$
	1600	41°13'.3	72°43'.8	LW + 1^h10^m	S--	13	--	none	--	JBF buoy $26.9<S<27.6$
	1615	41°12'.5	72°43'.6	LW + 1^h25^m	S--	12	--	8	--	S. of above $26.7<S<28.2$
	1630	41°11'.4	72°43'.6	LW + 1^h45^m	S--	19	--	10	--	S. of above $26.6<S<28.2$
200872	1030	41°10'.8	72°48'.0	HW + 2^h30^m	S--	18	--	5.0	--	Station 72-16 $26.8<S<27.7$
	1200	41°08'.9	72°48'.0	LW - 2^h00^m	S--	27	--	7.0	--	Station 72-10 $26.8<S<27.9$
	1230	41°08'.9	72°51'.6	LW - 1^h30^m	S--	22	--	6.0	--	Station 72-8 $26.3<S<27.6$
	1500	41°10'.8	72°52'.9	LW + 1^h00^m	S--	16	--	3	--	Station 72-14 $26.6<S<27.3$
230872	1034	41°12'.1	72°53'.8	HW + 0^h10^m	S,T,t	14.6	5.0	1.5	5.2	At N. H. sea buoy T_b = 17.7(isothermal)
	1050	41°11'.4	72°56'.8	HW + 0^h25^m	S,T,t	15	5.6	7.5	4.7	W x S of above
	1115	41°10'.8	72°59'.6	HW + 0^h50^m	S,T,t	12.6	6.8	8.5	3.9	W x S of above
	1140	41°10'.0	73°03'.4	HW + 1^h15^m	S,T,t	11.6	1.5	7.0	0.8	W x S of above T_b = 18°C, T_s = 26

Table 4, page 5

Date	Time	L	λ	Tide	Observed	Z_o	Z_t	Z_p	δ	Location/Remarks
	Q	N	W			m	m	m	mgm/cm^2	
230872 (Cont.)	1200	41°09'.5	73°05'.5	HW + 1^h35^m	S,T,t	9.0	1.0	7.5	0.4	Housatonic River Mouth T_b = 18
	1225	41°09'.3	72°59'.2	HW + 2^h00^m	S,T,t	16.2	5.4	5.4	8.0	W. of dump site
240872	1545	41°09'.4	72°43'.6	LW - 1^h30^m	S-t	30	14.3	21	17	5 mi. S.of Goose Rock
	1620	41°09'.4	72°39'.5	LW - 1^h00^m	S-t	29	13.0	15.5	22.5	3 mi. E. of above
	1649	41°09'.4	72°35'.5	LW - 0^h30^m	S-t	25	17	19	7	3 mi. E of above
010972	1025	41°10'.4	72°56'.3	LW + 1^h00^m	S,T,t	15.2	7.5	8.0	22	NW Control site ("A")
060972	1315	41°09'.0	72°53'.1	HW + 0^h45^m	S--	24	--	10.5	--	Dump site
080972	1300	41°10'.8	72°42'.7	HW + 1^h10^m	S-t	24	18	19	13	Station 72-18 $27.6<S<28.2$
	1400	41°07'.4	72°52'.9	HW + 2^h10^m	S-t	25	12.5	15	43.5	S. Control ("B") $26.9<S<27.5$
	1425	41°09'.0	72°53'.1	HW + 2^h30^m	S-t	22	13	14	33	Dump
	1445	41°10'.4	72°56'.3	HW + 3^h00^m	S-t	16	?	--	?	NW Control ("A")
150972	1509	41°10'.8	72°42'.7	HW - 1^h50^m	S,T,t	24	13	13	19	Station 72-18 $27.2<S<28.6$
	1630	41°07'.4	72°52'.9	HW - 0^h20^m	S,T,t	26	11.3	9.5	17	S. Control ("B") $27.1<S<28.0$

Table 4, page 6

Date	Time Q	L N	λ W	Tide	Observed	Z_o m	Z_t m	Z_p m	$\mathcal{S}$ mgm/cm²	Location/Remarks
150972 (Cont.)	1650	41°09'.0	72°53'.1	HW -	S,T,t	21.3	9.0	9.5	19	Dump Site
230972	1130	41°07'.4	72°52'.9	HW + 0^h15^m	S,T,t	26.5	19.8	--	50	S. Control ("B")
	1300	41°10'.4	72°56'.3	HW + 1^h30^m	S,T,t	16	4.6	--	3	NW Control ("A")
280972	1245	41°10'.8	72°42'.7	LW + 3^h35^m	S,T,t	24	11	none	22	Station 72-18
	1425	41°10'.8	72°45'.4	HW - 1^h15^m	S,T,t	20	12	9	45	Station 72-17
021072	1515	41°09'.0	72°53'.1	LW + 2^h00^m	S,T,t	22	7	none	3	Dump site
	1655	41°07'.4	72°52'.9	LW + 3^h30^m	S,T,t	25	4	12	3	S. Control site
	1745	41°10'.4	72°56'.3	LW + 4^h30^m	S,T,t	16	--	none	0	NW Control site

Notes: "Dump site ("A")" refers to the location of buoy "A" placed by the Corps of Engineers in May 1972 and removed to the NW Control site at the end of August.

"JBF buoy" is the site of the benthic recolonization experiment south of Leetes Island.

T_b = Water temperature at the bottom; T_s, at the surface

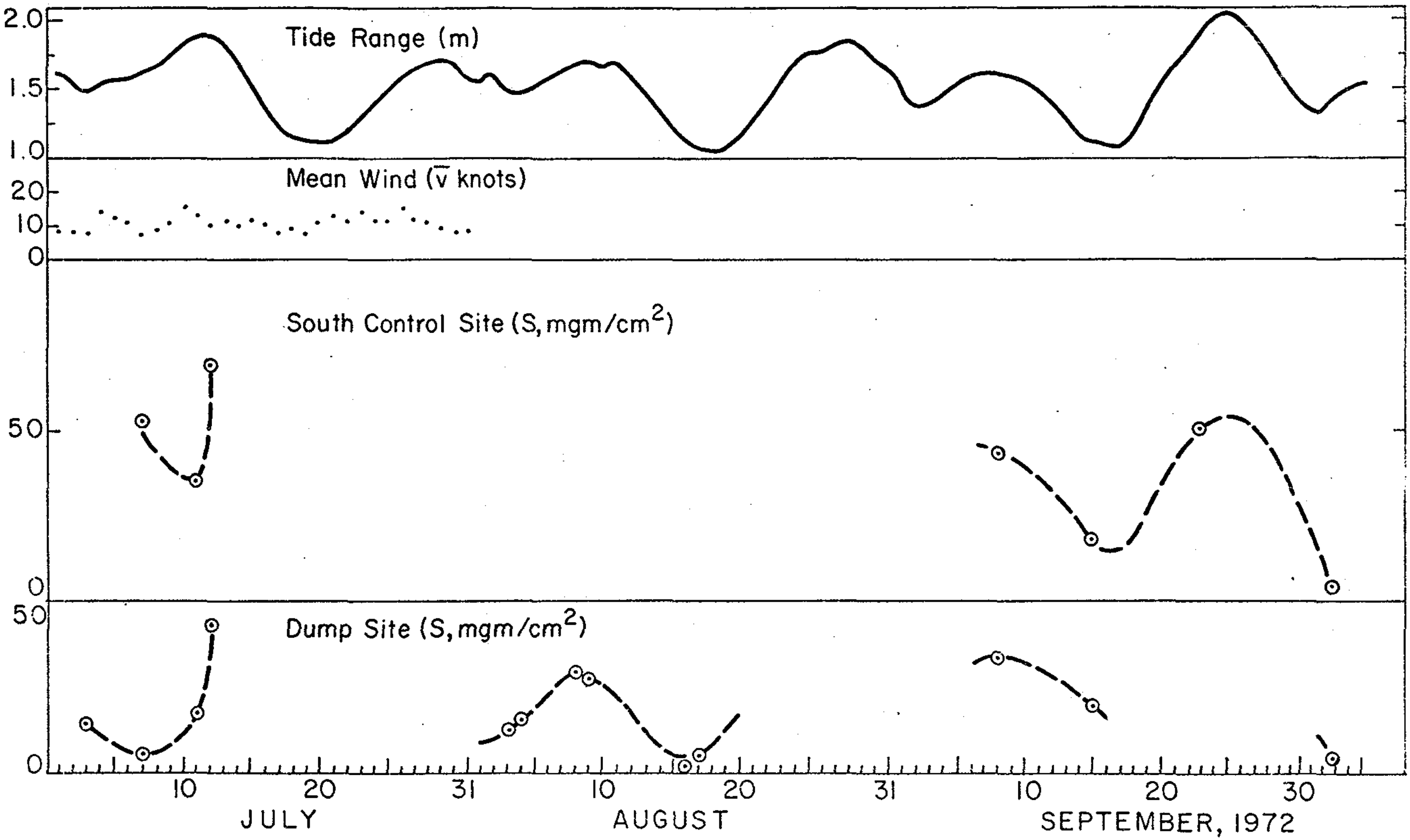
S = Salinity, ^{o}/oo.

with the current speed at the time of observation. This shows that the resuspended sediment does not settle out of the water column during the periods of low current speeds occurring near the time the current turns. For comparison with $\mathscr{S}$ there is plotted in Fig. 9 the greatest tidal range and mean wind speed (as recorded at Stratford Point) for each day. Although the turbidity data are not as complete as desired, it is clear that the principal factor controlling sediment resuspension is the speed of the tidal streams over a period of days, as indicated by the tide range. Resuspension is large during springs and weak during neaps. The dependence of resuspension on tidal stream speed exceeds any effect that sea state had during the study period. No major storm events occurred during July, August or September, but the northeast gale of 7 October (wind speeds to 40 knots) did not increase the observed amount of resuspended sediment at the dump or control sites.

Even casual observation shows that waves are responsible for the generation of strong turbidity in the shallow waters of harbors and bays along the north shore of Central LIS. There exists the possibility that such wave-induced turbidity might be mistaken for material transported from the dump site or, in New Haven Harbor, raised by the dredging operations. To provide data for comparison with observations to be made while dredging and dumping are in progress, transmittance measurements were made to establish the levels of naturally occurring turbidity at stations between the dump site and adjacent shore areas, and in shallow bays and harbors.

The turbidity stations made on 4, 11, and 23 August (see Table 4) surround the shoreward sides of the spoil ground. These were made over a period in which the tidal stream speeds inferred from tide heights show only

Figure 9. Total amount of resuspended sediment, $\mathscr{S}$ present at the dump and south control sites during the study period. For comparison, the mean wind speed determined by the National Weather Service at Stratford Point and the greatest range of the tide height each day is shown.

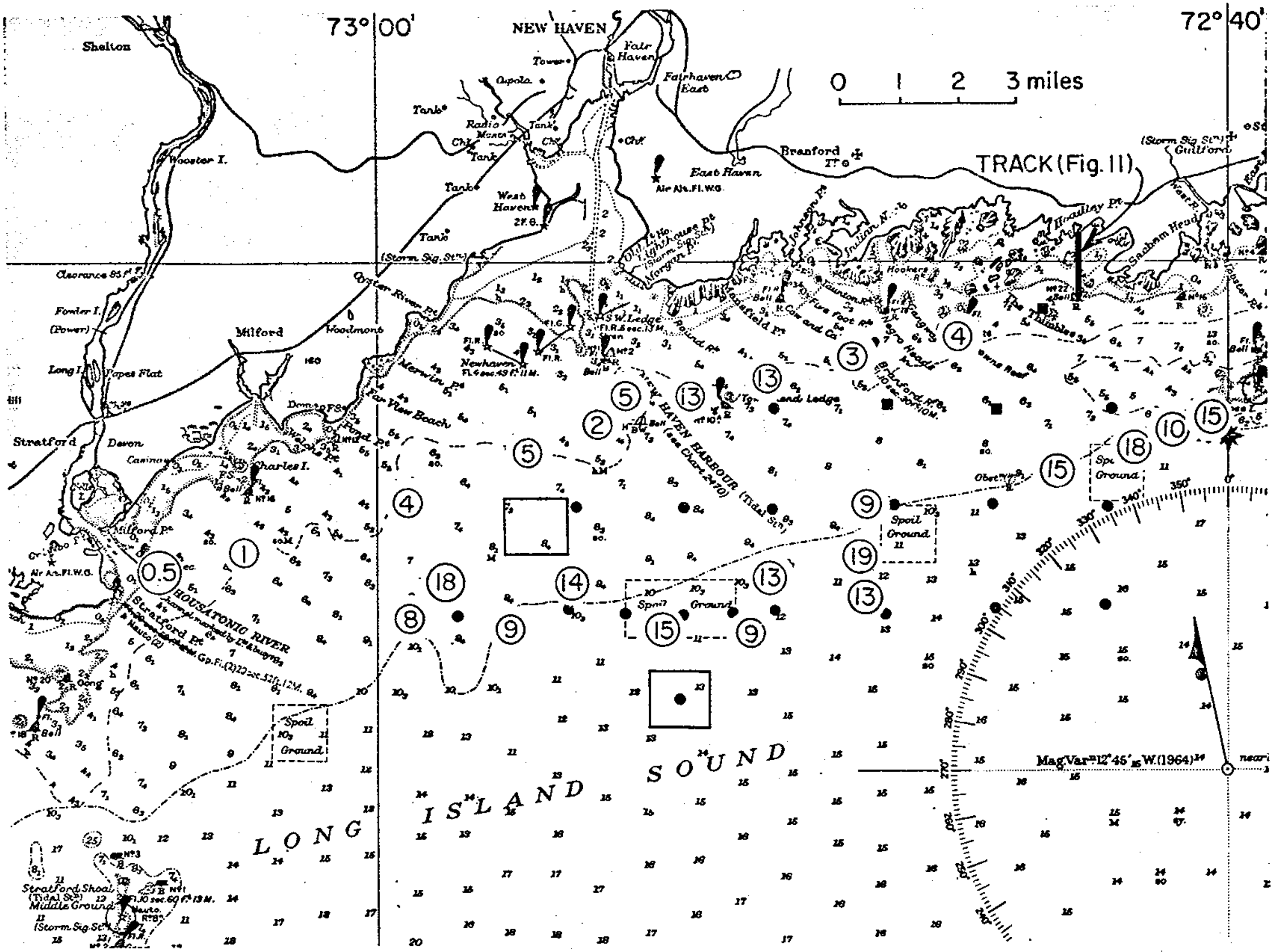


2.0
1.5
1.0
Tide Range (m)
Mean Wind ($\overline{v}$ knots)
20
10
0
South Control Site (S, mgm/cm^2)
50
0
Dump Site (S, mgm/cm^2)
50
0
10
20
31
10
20
31
10
20
30
JULY
AUGUST
SEPTEMBER, 1972

relatively small changes (see Fig. 9) so an attempt to correct for this factor when intercomparing the observations is probably unnecessary. The spatial distribution of resuspended sediment is shown in Fig. 10. It is generally lowest where the tidal streams are weakest. Any sediment transported from the dump site to the shore area would have to pass this array of stations and so could be detected as excess turbidity; observation of the turbidity concentration gradient should identify the source of excess turbidity.

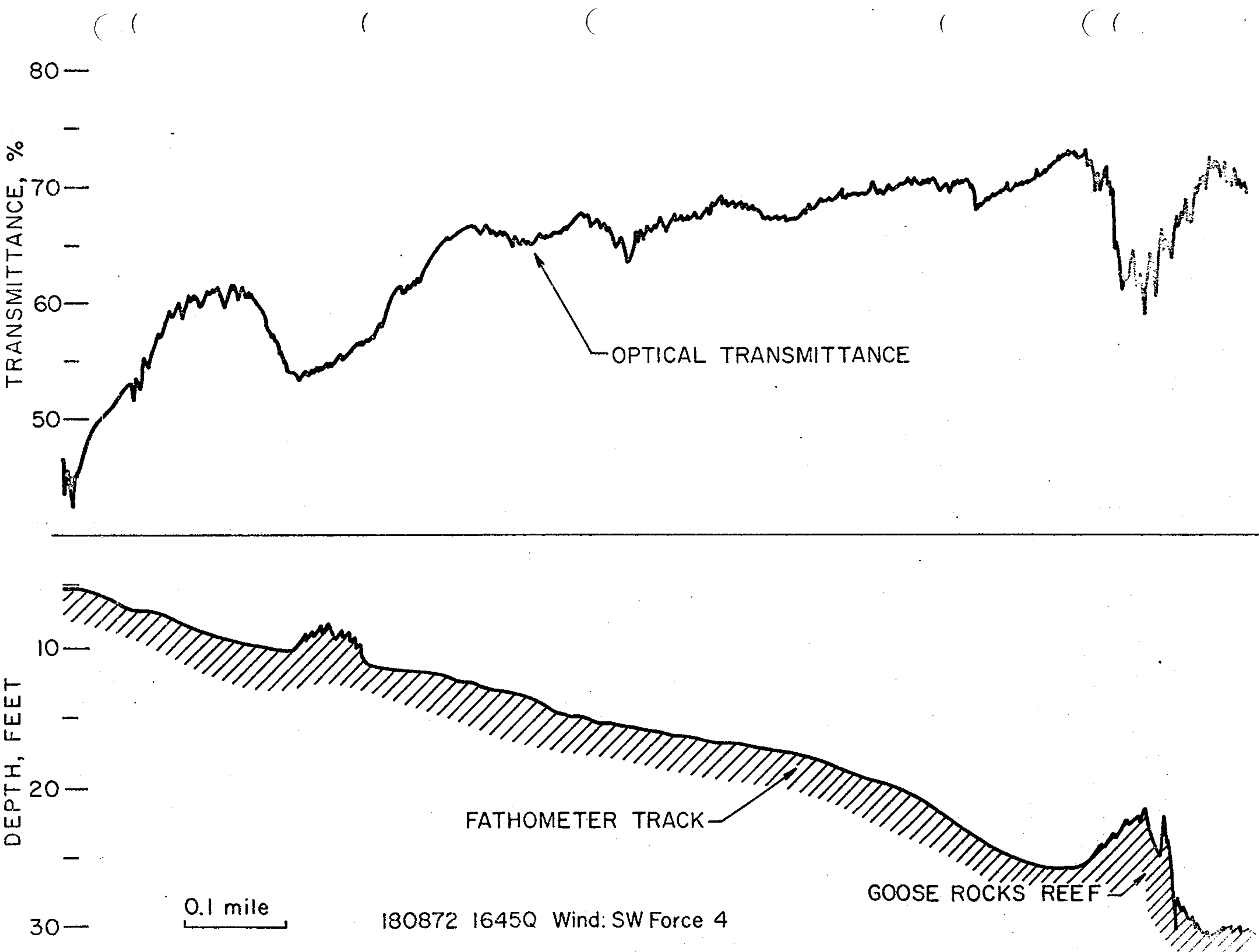
The resuspension of sediment by wave action along the shore was studied in the bay between Sachem Head and Outer Island. This is an exposed bay well removed from the sites of industrial activity, dredging, or dumping operations and so will serve as an excellent "control site" for this phenomenon. Two types of observations have been made, a series of near-surface turbidity measurements at stations ranging from shallow to deep water, and continuous records of the turbidity gradient. A continuous turbidity track run from the mouth of Little Harbor to Goose Rocks is shown in the upper part of Fig. 11; in the lower part the corresponding fathometer record is shown. The bottom of the bay is mud containing about 20% sand and is pierced by the two rocky outcrops shown by the fathometer record. The turbidity track shows three general features: First, there are local increases in turbidity at the two rocky areas. This is interpreted as due to enhanced resuspension of the surrounding bottom by locally increased turbulence in the tidal stream (a small rip forms at Goose Rocks on the ebb). Second, there is a regular increase in turbidity as the water shoals, and, finally, a sharp increase when the water depth reaches 6 feet. This corresponds approximately to one half the wavelength of the sea running in the bay at the time the track was made. Wave-induced turbidity is generated when the water depth is about

Figure 10. Distribution of resuspended sediment as observed on 4, 11, and 23 August 1972. For each location the total suspended sediment concentration, $\mathcal{S}$, in mgm/cm^2, is plotted. To the east of the study area the Sound bottom becomes nearly pure sand and $\mathcal{S} \to 0$. To the northwest of the New Haven spoil ground $\mathcal{S}$ is small because the tidal streams are relatively weak.



73° 00'
72° 40'
NEW HAVEN
0 1 2 3 miles
TRACK (Fig. 11)
Shelton
Wooster I.
Milford
Stratford
Devon
Charles I.
Milford Pt.
Woodmont
Merwin Pt.
Fair View Beach
West Haven
East Haven
Fair Haven
Fairhaven East
Branford
Guilford
Sachem Head
The Thimbles
Hookers
NEW HAVEN HARBOUR (Tidal Sts.)
(see Chart 2470)
HOUSATONIC RIVER
Stratford Pt.
Spoil Ground
Stratford Shoal
Middle Ground
LONG ISLAND SOUND
Mag.Var.n 12°45' W.(1964)
0.5
1
4
5
2
5
13
13
3
4
18
8
9
14
15
9
13
19
13
9
15
18
10
15

Figure 11. Turbidity track run southwards from Little Harbor (see Fig. 10) and the corresponding fathometer record.


80
70
60
50
TRANSMITTANCE, %
OPTICAL TRANSMITTANCE
10
20
30
DEPTH, FEET
FATHOMETER TRACK
GOOSE ROCKS REEF
0.1 mile
180872 1645Q Wind: SW Force 4

equal to half the wavelength, as might be expected on the basis of small amplitude wave theory. It is carried out of the bay, in this case by the ebb current, its concentration being reduced in proportion to the water depth by simple dilution. (There would be no significant loss of suspended sediment by settling over this distance as it requires several days for water in this area to clear after being agitated by waves.) Within the bay, the vertical distribution of turbidity is nearly constant; turbulent mixing is strong enough to distribute suspended sediment almost uniformly through the water column.

A similar turbidity track run through New Haven Harbor is shown in Fig. 12. The track followed is plotted in Fig. 13, which identifies the reference points in Fig. 12. The track was run near slack low water on a day when an easterly wind raised breaking waves outside the harbor. The general turbidity level throughout the harbor is high; it is particularly high near the Tomlinson bridge, mark 1 on the chart, because of pulp mill effluent entering the harbor from the Mill River, and again in the shallow water of the outer harbor where wave induced turbidity is present. To date, this track has been run three times:

Table 5

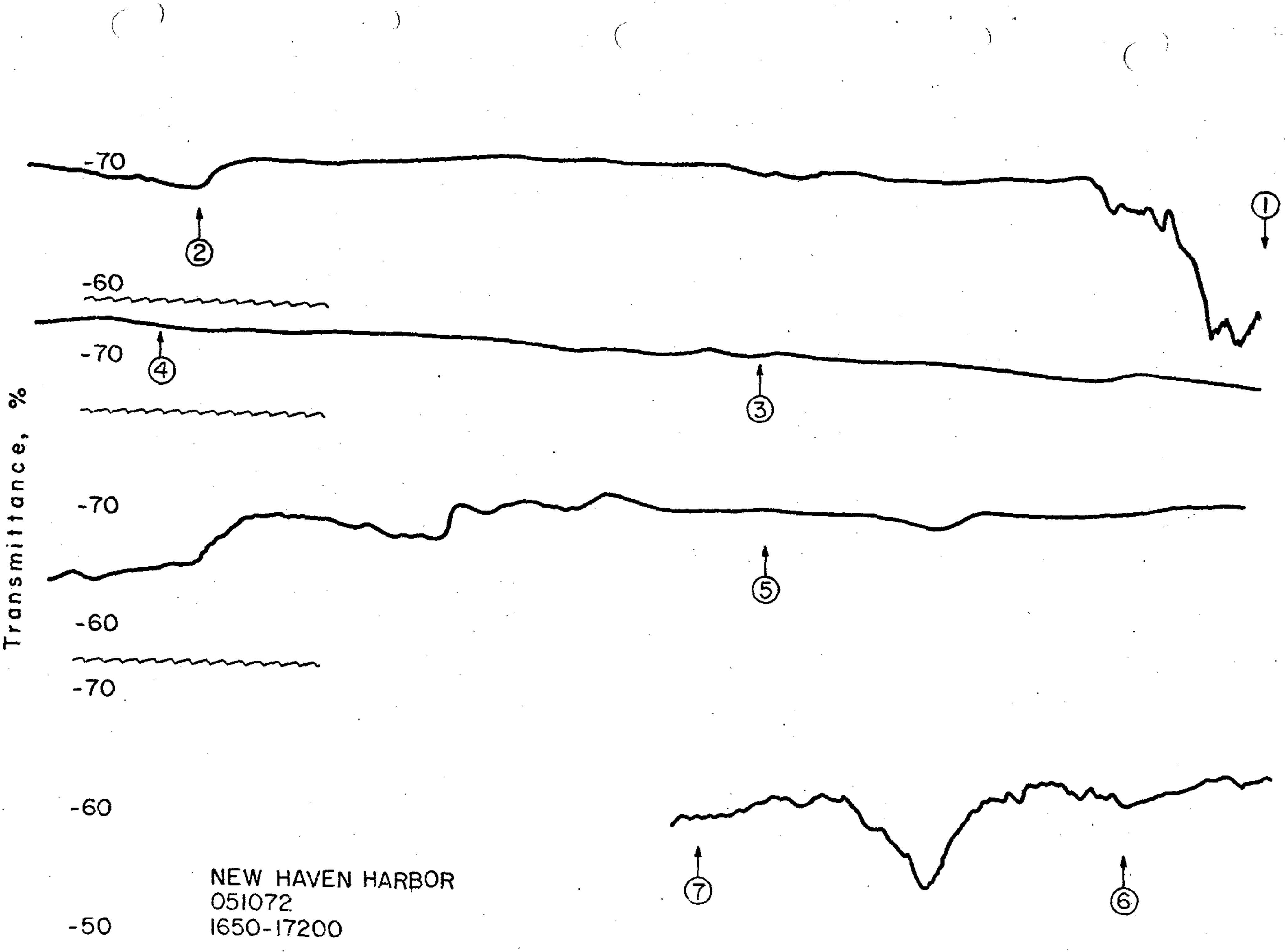
Turbidity Tracks Run in New Haven Harbor

11 August 1972, 1030 - 1113 Q

19 September 1972, 1455 - 1530

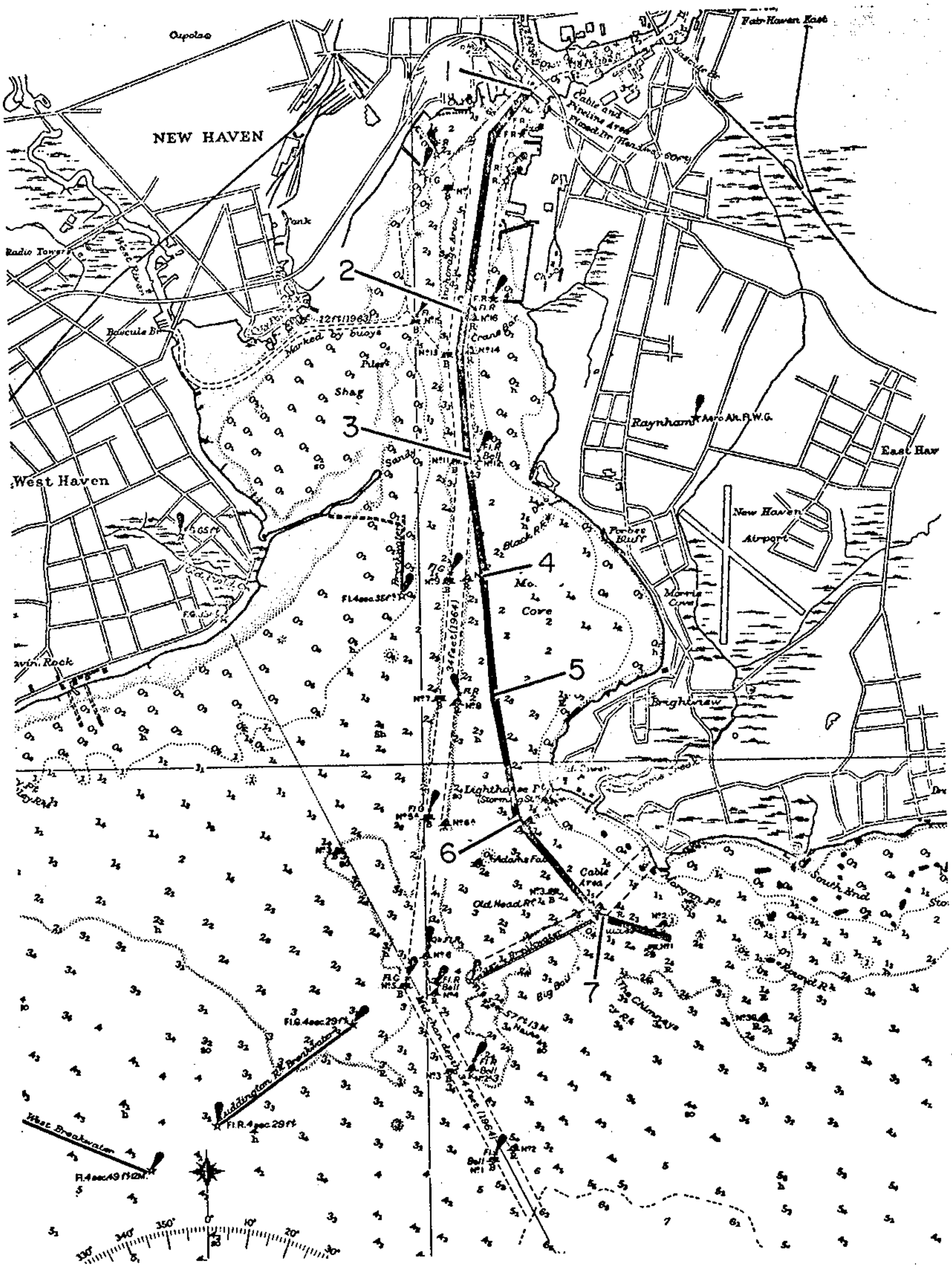
5 October 1972, 1650 - 1720

Figure 12. Continuous turbidity record through New Haven Harbor made on 5 October 1972. The record is broken into four segments each of which runs from right to left. Position check points indicated by numbers are shown in Fig. 13.



Transmittance, %
-70
-60
-70
-70
-60
-70
-60
-50
1
2
3
4
5
6
7
NEW HAVEN HARBOR
051072
1650-17200

Figure 13. Track followed in making the turbidity record of Fig. 12.

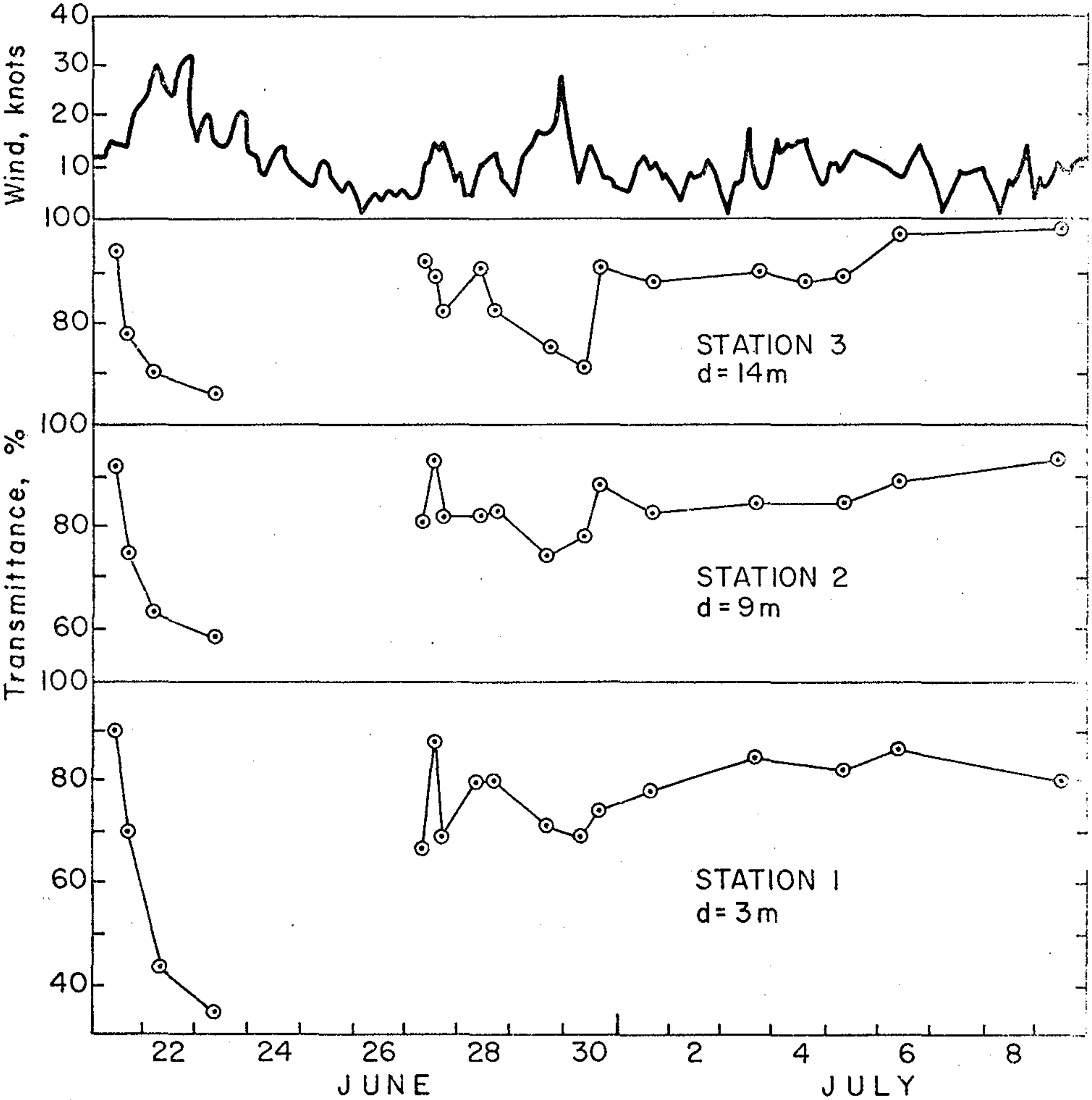


NEW HAVEN
West Haven
Raynham
New Haven Airport
Marked by buoys
Shag
Sandy
Black Rk.
Mo. Cove
Morris Cove
Forbes Bluff
Lighthouse Pt.
Cable Area
Morgan Pt.
South End
Old Head Rf.
Big Bol
The Chimneys
Luddington Rk. Breakwater
West Breakwater
Cable and Pipeline Area
Radio Towers
Bascule Br.
Cupola
Fair Haven East
Crane Bar
1
2
3
4
5
6
7

Serial observations of turbidity at stations where the mean water depth is 3, 9, and 14 meters are shown in Fig. 14. These stations are located along an extension of the track shown in Fig. 10. For comparison, wind velocities recorded at the National Weather Service station on Stratford Point are also shown. It is clear that the periods of high turbidity in shallow water (low transmittance) are the periods of high winds and that with continued high wind turbidity builds up over a period of about a day. The deeper the water, the less is the wave-induced turbidity. Between the end of June and 30 September, there were no storms of sufficient intensity to permit further study of wave-generated turbidity in the deeper waters of Central LIS.

<u>Mechanical Properties of the Bottom</u>. Conditions favoring the retention of spoil on the bottom at the place where it has been dumped are low water speeds (from tidal streams or waves) and a soft bottom. The results reported above show that the speed of tidal streams at the New Haven spoil ground is relatively high; it is anticipated that the bottom at this site may be agitated by waves in winter storms. A favorable characteristic of this site, however, is the soft bottom found in much of Central LIS. We measure bottom "hardness" as the slope of the force-displacement curve generated by driving a cylindrical indentor into the bottom (Gordon, 1972). The hardness of the bottom at and around the New Haven spoil ground was measured with the penetrometer described in the above paper. Some additional measurements were made on diver-collected cores in the laboratory with an Instron testing machine. These cores are collected without disturbance of the sediment-water interface.

Figure 14. Repeated turbidity measurements made at stations along a track extending south from Little Harbor (see Fig. 10). Measurements are made 1 meter below the surface. For comparison, the wind speed at Stratford Point is plotted.



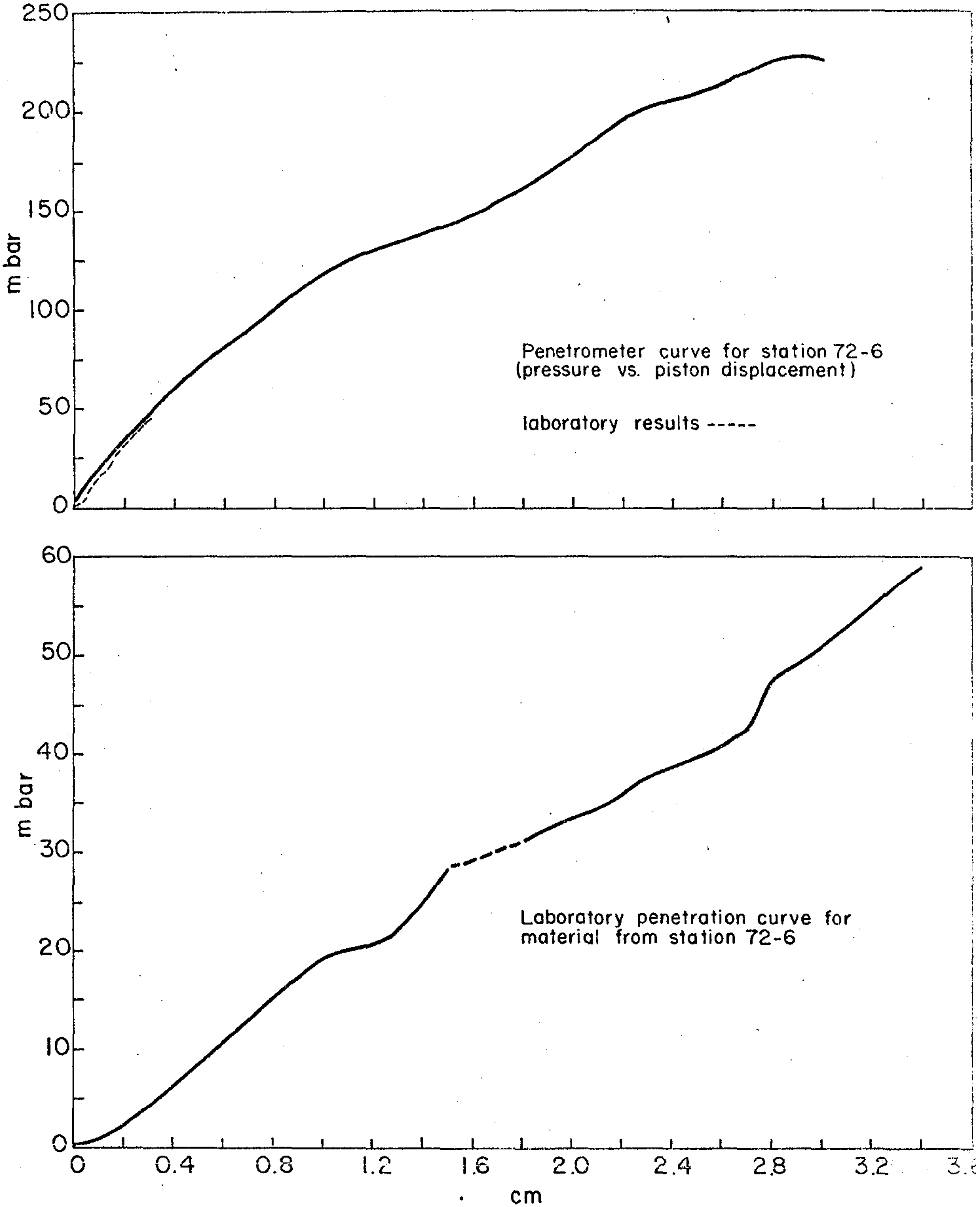
Wind, knots
Transmittance, %
STATION 3
d = 14m
STATION 2
d = 9m
STATION 1
d = 3m
JUNE
JULY

The form of the penetration curve found for undisturbed Central LIS mud bottom is illustrated by the example in Fig. 15, where a curve obtained on station with the penetrometer and in the laboratory on a diver-collected core are compared. Agreement between the two curves is very good. The surface sediment has no cohesive strength, as evidenced by the lack of intercept on the stress axis. Below a depth of 1mm an approximately uniform hardness (constant slope) is found. At some stations hardness increases--jumps or changes in slope of the penetration curve--are found. Examination of cores indicates that these are caused by layers of shell, of sand, or of foreign material below the surface.

The mechanical tests show that there is no cohesion of the material at the sediment-water interface. This material will be taken into suspension by tidal currents when the water velocity reaches a critical value dependent on particle size and density. Examination of the interface photographs shows that this material is biologically reworked, oxidized, and has a granular texture. The mechanical tests and interface photographs show that there is a large supply of unbound granules on the bottom. The amount of tidal resuspension is limited, therefore, not by the supply of suspendable material but by current strength. This interpretation is supported by the observed presence of erosional features on the bottom, as seen in Plate 16.

The relationship between hardness and bottom character is illustrated by data taken along an E-W track that crosses the eastern sand-mud boundary of Central LIS. These data are summarized in Table 6. (The hardness for pure sand is from laboratory data.) In this area bottom hardness is determined primarily by sand content, and increases rapidly once the sand fraction exceeds about 1/3.

Figure 15. Penetration curves obtained for the bottom at Station 72-6. In the upper graph the penetrometer curve obtained on station is the solid line. The dashed line is obtained from a diver-collected core tested in the laboratory. The laboratory test data are shown on an expanded scale in the lower graph.



250
200
150
100
50
0
m bar
Penetrometer curve for station 72-6
(pressure vs. piston displacement)
laboratory results -----
60
50
40
30
20
10
0
m bar
Laboratory penetration curve for
material from station 72-6
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
cm

Table 6

Hardness and Sand Content of Bottom

Station	L	λ	H	Sand Fraction
72-71	41°12'.5 N	72°49'.0 W	21 mbar/cm	15%
72-72	41°12'.5 N	72°47'.0 W	20 mbar/cm	33%
72-73	41°12'.5 N	72°44'.0 W	66 mbar/cm	47%
72-74	41°12'.5 N	72°37'.1 W	225 mbar/cm	80%
--	--	--	400 mbar/cm	100%

The bottom hardness measurements made with the penetrometer are summarized in Table 7. The location of each penetration measurement is given in terms of the range in meters from Stratford Point, R_1, and from the Old Tower on Lighthouse Point, R_2. The first value of H recorded is that immediately below the surface; when a hard or soft layer is encountered the depth of this layer below the surface is recorded as d. The principal result to emerge from these data is that the bottom at and to a distance several miles around the dump site is uniformly soft. It is a favorable area for the retention of sand or coarser, dumped material. A second, and important, result is that where sand has been previously dumped, this now appears as a hard horizon with a covering of soft, sand-free sediment at least 4 cm thick over it. This is interpreted as new sediment brought into the area and deposited in the years since the last use of this dump site.

Bathymetric Survey. During May 1972 a detailed bathymetric survey of two square-mile areas centered on the dump site and the south control site was made by the Corps of Engineers. Repeated surveys will show the distribution of dumped material when corrected for water height from tide gauge measurements. (A correction for bottom compaction due to the weight of dumped material can be made from the known value of H.) An alternate method of detecting material deposited on the bottom is by comparison with a series of long fathometer tracks run across the dump ground. The charted 10 fathom curve runs through this area in the direction 088°-268° magnetic. A series of tracks was run in this direction starting and ending well clear of the area where material had been dumped in the past. This establishes a base line at the end of each track relative to which any subsequent changes in

Table 7

Summary of Penetrometer Measurements

Date	Time (Q)	R_1 (meters)	R_2 (meters)	Station	Hardness (mbar/cm)	d (cm)	Other Data Taken
180772	1322	18634	11527	A	21; 46	4.5	1 piston core taken
	1421	18861	14107	B	17	--	2 piston cores taken
	1512	20324	11540	72-8	20	--	1 piston core taken
190772	1028	19062	14766	72-95	21	--	1 piston core and 1 short gravity core taken
	1037	19096	14794	72-95	39	--	
	1122	18075	14202	72-78	16	--	1 piston core taken
	1250	18666	13015	72-52	25	--	1 piston core taken
	1339	19615	13916	72-76	18; 33	4.5	1 short gravity core taken
	1445	11302	12471	72-5	62	--	1 short gravity core taken
	1522	15005	11357	72-6	10	--	1 short gravity core taken
	1530	15005	11357	72-6	6	--	
250772	1019	18591	14054	B	15; 24	6	2 photos (Station 1)
	1033	18588	14050	B	40	--	photo (Station 3)
	1103	18589	14020	B	25	--	photo (Station 4)
	1107	18589	14020	B	40	--	
	1118	18624	14053	B	20	--	photo (Station 5)
	1139	18638	14057	B	22	--	photo (Station 6); 2 cores

Table 7, page 2

Date	Time (Q)	R_1 (meters)	R_2 (meters)	Station	Hardness (mbar/cm)	d (cm)	Other Data Taken
250772 (Cont.)	1343	18215	09888	72-100	20; 53	6	photo (Station 7)
	1351	18215	09888	72-100	16; 6 (?)	8	
	1401	18240	09888	72-100	11	--	photo (Station 8)
	1412	18268	09878	72-100	11	--	photo (Station 9)
	1422	18275	09873	72-100	19	--	photo (Station 10)
	1432	18283	09869	72-100	12	--	photo (Station 11)
	1441	18290	09873	72-100	14; 24	5	photo (Station 12); 2 cores
260772	1018	18555	08367	72-14	26; 6	5	3 cores taken
	1417	17000	11543	72-7	21	--	2 cores taken
	1441	21973	12263	72-9	18	--	2 cores taken
	1537	25700	14270	72-10	50	--	2 cores taken
	1645	29255	16635	72-11	31 (?)	--	2 cores taken
	1703	19079	14530	72-17	17	--	1 core taken
	1714	19333	14650	72-17	23; 57	6	
	1845	24713	11034	72-16	21	--	2 cores taken
	1910	22016	08973	72-15	17; 10	9	
310872	1013	14182	08881		6	--	Photos taken at: 14185, 08878; 14183, 08872; 14181, 08878; 14181, 08871; 14163, 08861
	1021	14182	08880		13	--	
	1055	14190	08876		12; 3	7	
	1056	14187	08875		20; 6	7	Core taken at: 14163, 08861
	1107	14180	08880		30; 3; 9	7; 15	

Table 7, page 3

Date	Time (Q)	R_1 (meters)	R_2 (meters)	Station	Hardness (mbar/cm)	d (cm)	Other Data Taken
310872 (Cont.)	1110	14180	08880		20; 3; 15	7; 19	
	1140	14186	08872		21	--	
	1157	14186	08872		17	--	
	1401	18368	11151		22; 26	6	Photos taken at: 18372, 11150; 18362, 11150; 18356, 11144; 18348, 11137; 18344, 11140
	1404	18368	11151		19; 28	6	
	1418	18364	11148		15	--	
	1434	18360	11144		26; 16	2	
	1448	18349	11141		14	--	
	1456	18335	11143		10	--	
070972	1017	24850	08511	72-71	24; 10; 3	7; 14	2 photos; grab sample and 1 core
	1025	24850	08513	72-71	21	--	
	1129	27436	11024	72-72	20	--	2 photos; grab sample; core
	1258	31540	15021	72-73	45; 100	4	3 photos; grab sample; core
	1301	31540	15021	72-73	66 (good only to 4 cm)	--	
	1420	~	~	72-74	225; 300	1	2 photos; grab sample; core
	1437	~	~	72-74	200	--	
	1617	32401	15048	JBF	180; 270	2	4 photos; grab sample; core
	1620	32401	15048	JBF	100; 270; 120	1.8; 2.2	

bottom configuration can be detected. A long north-south track run up to the spoil area (on 26 July) shows that the natural bottom of Central LIS is smooth and has a very regular slope. Material previously dumped on the bottom now shows up as an irregular profile rising above the natural slope. Examination of these tracks therefore indicates where spoil has been dumped in this area in the past. A contour map showing the excess elevation above the natural slope is shown in Fig. 16. It is clear that much dumping in the past was done well outside the designated spoil ground.

All fathometer tracks run are listed in Table 8. For each track the range coordinates for a series of check points along the track were pre-computed. The ship's heading was corrected on passing each of these check points so as to minimize the departure from the straight track. Experience showed that the ship could be piloted along these tracks with deviations held to less than 10 meters in almost all cases. Good reproducibility was found on tracks run more than once. Piloting is facilitated on the E-W tracks because the tidal current is either ahead or astern. However, a few north-south tracks were run so as to better define the existing irregular topography resulting from past dumping.

Figure 16. Contours of excess elevation above the natural bottom surface in the vicinity of the New Haven spoil ground. Excess elevation is interpreted as material previously dumped. This interpretation is confirmed by the presence of arkose sand and other foreign materials in cores taken at the peaks shown in the figure. The contour interval is one foot and the heavy lines are the designated boundaries of the spoil ground.

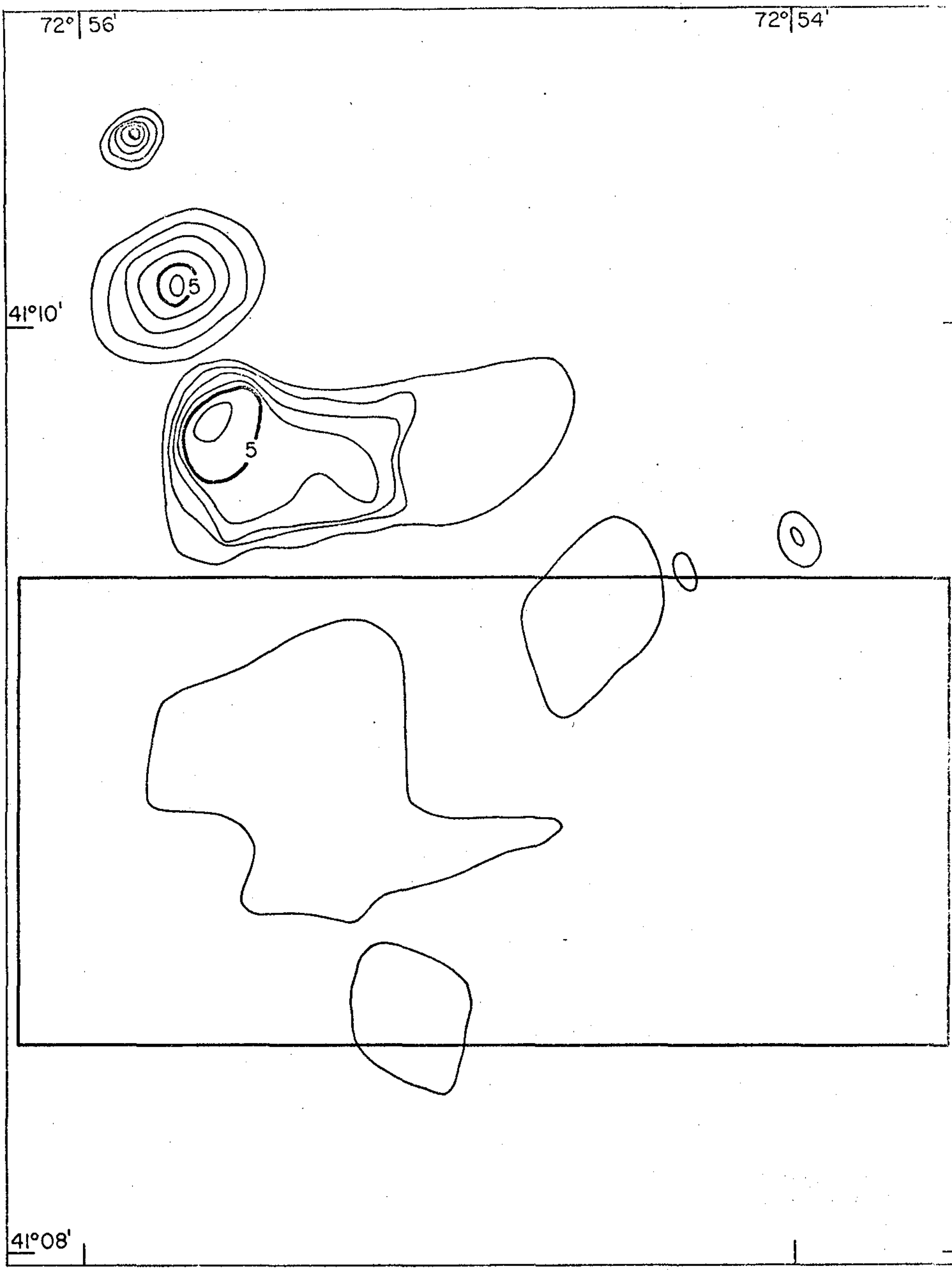

72° 56'
72° 54'
41°10'
41°08'
5
5

Table 8

Fathometer Tracks Run by the Manamet

Date	Number of Tracks Run	Start R_1/R_2	Start Time	Finish R_1/R_2	Finish Time	Heading (°mag.)	Track Designation
180772	2	15974/11668	1057 Q	21794/11251	11:22 Q	088	
		19402/14302	1145	17728/8132	12:10	358	
260772	1	23458/24611	1316	19907/20018	13:48	009	
280772	6	15716/12048	(1534)	21524/11454	(1552*)	088	EW 7
		15722/11988	(1638)	20426/11322	(1655)	088	EW 7
		20528/11254	(1700)	16570/11601	(1728*)	268	EW 7A
		21525/10994	(18:08)	16098/11358	(1835)	268	EW 8
		16168/10303	(1845)	20095/9821	(1901)	088	(EW 10)
		17950/8340	(1922)	18732/12001	(1938)	358	(NS 7)
060972	5	15756/11873	(1405)	21516/11290	(1425)	088	(EW 7A)
		21958/11225	(1434)	15667/11763	(1512)	268	(EW 7B)
		15659/11543	(1554)	21527/10974	(1618)	088	(EW 8)
		21543/10611	(1634)	16132/10980	(1704)	268	(EW 8B)
		16114/10334	(1720)	21593/10037	(1737)	088	(EW 10)

Table 8, page 2

Date	Number of Tracks Run	Start R_1/R_2	Start Time	Finish R_1/R_2	Finish Time	Heading (°mag.)	Track Designation
090972	2	21024/11475	0939	15695/12047	0956	268	EW 7
		15743/12207	(1016)	21511/11622	(1036)	088	(EW 6B)
120972	1	21590/10038	(--)	15125/10720	(--)	088	(EW 10)
130972	8	15778/12396	(1016)	21511/11947	(1048)	088	(EW 6)
		22136/12884	(1057)	15889/13628	(11:24)	268	(EW 4)
		19212/13856	(1320)	17849/8826	(1337)	178	(NS 6B)
		17988/8344	(1341)	19475/13887	(1358)	358	(NS 7)
		19075/14298	(1148)	17428/8288	(1208)	178	(NS 6)
		17551/8306	(1256)	19109/13832	(1314)	358	(NS 6A)
		19654/14412	(1406)	18120/8337	(1425)	178	(NS 7A)
		18785/8492	(1437)	20545/14561	(1457)	358	(NS 8B)

Notes: R_1 is the range in meters from Stratford Point Light.

R_2 is the range in meters from the Old Toweron Lighthouse Point.

BENTHIC BIOLOGY AND HABITAT DOCUMENTATION

The complete biological sampling program for the New Haven Harbor dredging project will involve three phases: 1) establishing a pre-dredge and pre-dump data base for the New Haven ship channel, the designated dump site, a control site one mile south of the dump site, and a control site approximately 3 miles northwest of the dump site, 2) sampling these same areas during dumping, and 3) continuing benthic sampling after dumping has been completed to determine rates and sequences of recolonization.

The pre-dredge and pre-dump data collection has been completed. At the time of preparation of this report, only samples from the dump site have been worked to completion and are presented here. As faunal identification proceeds, report supplements will be submitted on the biology of the channel and control areas.

<u>Sampling Methods</u>. A rectangular grid or matrix sampling pattern was established for the dump and control sites. This type of pattern was selected as it permits rapid and accurate location and relocation of sampling stations on the microwave range grid established by the Corps for surveying Central Long Island Sound. The sample areas are one mile in length on each side. Stations are located every 300 meters. Sample station numbers, ranges, and locations on the Connecticut Grid coordinate system are listed in Table 9. Not all stations were occupied; thirty-one samples were taken at the dump and control sites in the following pattern:

Table 9

Biological Sample Stations on Dump Site

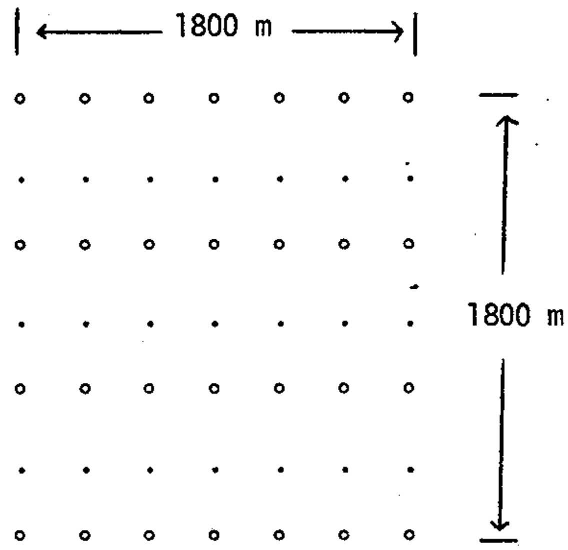
Station Number	Ranges R_1 (m)	R_2 (m)	Grid Coordinates (E)	(N)
1	17700.	10300.	560618.8	117784.4
2	18000.	10300.	561600.6	117887.4
3	18300.	10300.	562581.6	118019.3
4	18600.	10300.	563561.4	118180.5
5	18900.	10300.	564539.9	118371.3
6	19200.	10300.	565517.0	118591.9
7	19500.	10300.	566492.3	118842.7
8	17700.	10600.	560636.1	116797.8
9	18000.	10600.	561619.4	116898.4
10	18300.	10600.	562602.2	117027.5
11	18600.	10600.	563584.4	117185.0
12	18900.	10600.	564565.7	117371.4
13	19200.	10600.	565545.9	117587.0
14	19500.	10600.	566524.9	117832.2
15	17700.	10900.	560636.6	115809.9
16	18000.	10900.	561621.6	115908.0
17	18300.	10900.	562606.4	116033.7
18	18600.	10900.	563591.1	116187.3
19	18900.	10900.	564575.3	116369.2
20	19200.	10900.	565558.9	116579.6
21	19500.	10900.	566541.6	116819.1

Table 9, page 2

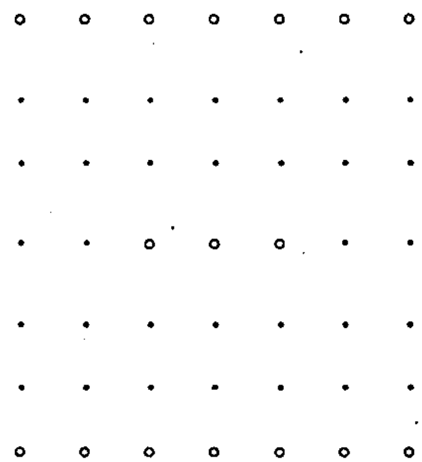
Station Number	Ranges R_1 (m)	R_2 (m)	Grid Coordinates (E)	(N)
22	17700.	11200.	560620.3	114820.8
23	18000.	11200.	561607.1	114916.0
24	18300.	11200.	562594.2	115038.2
25	18600.	11200.	563581.5	115187.8
26	18900.	11200.	564568.8	115364.9
27	19200.	11200.	565555.7	115570.0
28	19500.	11200.	566542.1	115803.4
29	17700.	11500.	560587.0	113830.6
30	18000.	11500.	561575.8	113922.6
31	18300.	11500.	562565.4	114041.1
32	18600.	11500.	563555.4	114186.3
33	18900.	11500.	564545.8	114358.5
34	19200.	11500.	565536.3	114558.1
35	19500.	11500.	566526.6	114785.6
36	17700.	11800.	560536.8	112839.4
37	18000.	11800.	561527.8	112928.0
38	18300.	11800.	562519.9	113042.5
39	18600.	11800.	563512.8	113183.2
40	18900.	11800.	564506.4	113350.4
41	19200.	11800.	565500.4	113544.4
42	19500.	11800.	566494.7	113765.8
43	17700.	12100.	560469.4	111847.4
44	18000.	12100.	561462.8	111932.3

Table 9, page 3

Station Number	Ranges R_1 (m)	R_2 (m)	Grid Coordinates (E)	(N)
45	18300.	12100.	562457.6	112042.6
46	18600.	12100.	563453.5	112178.6
47	18900.	12100.	564450.4	112340.6
48	19200.	12100.	565448.2	112528.9
49	19500.	12100.	566446.4	112744.0



Of these 31 samples, 17 were worked to completion:



The 14 samples not identified are preserved and in storage, available for adding data if required. The harbor channel stations were selected near navigation buoys and are essentially the same sampling sites as the USCE coring stations. The benthic samples from the channel therefore carry the same station letters and numbers as the coring stations.

All samples were taken with a 0.15 M^2 Van Veen grab. Maximum depth of bite of this grab is 28 cm. In most cases, sediment completely filled the bucket. After recovery, the 0.15 M^2 sample was sieved through a 1.0 mm mesh screen. Retained organisms were preserved in 10% buffered formalin and stained with rose bengal, a bright red vital stain. This stain increases picking efficiency as small transparent polychaetes and amphipods are more easily seen during the time-consuming separation process. After about 24 hours, the samples were transferred from formalin to 80% ethanol. After identification, calcareous species were decalcified in 10% HCl. All species were then dried at 60°C overnight and weighed for decalcified dry weight biomass. Only species represented by $\gtrsim$ 0.1 g were weighed,as errors on measuring smaller quantities are great. These dried samples were then given to Dr. Turekian for trace metal analysis.

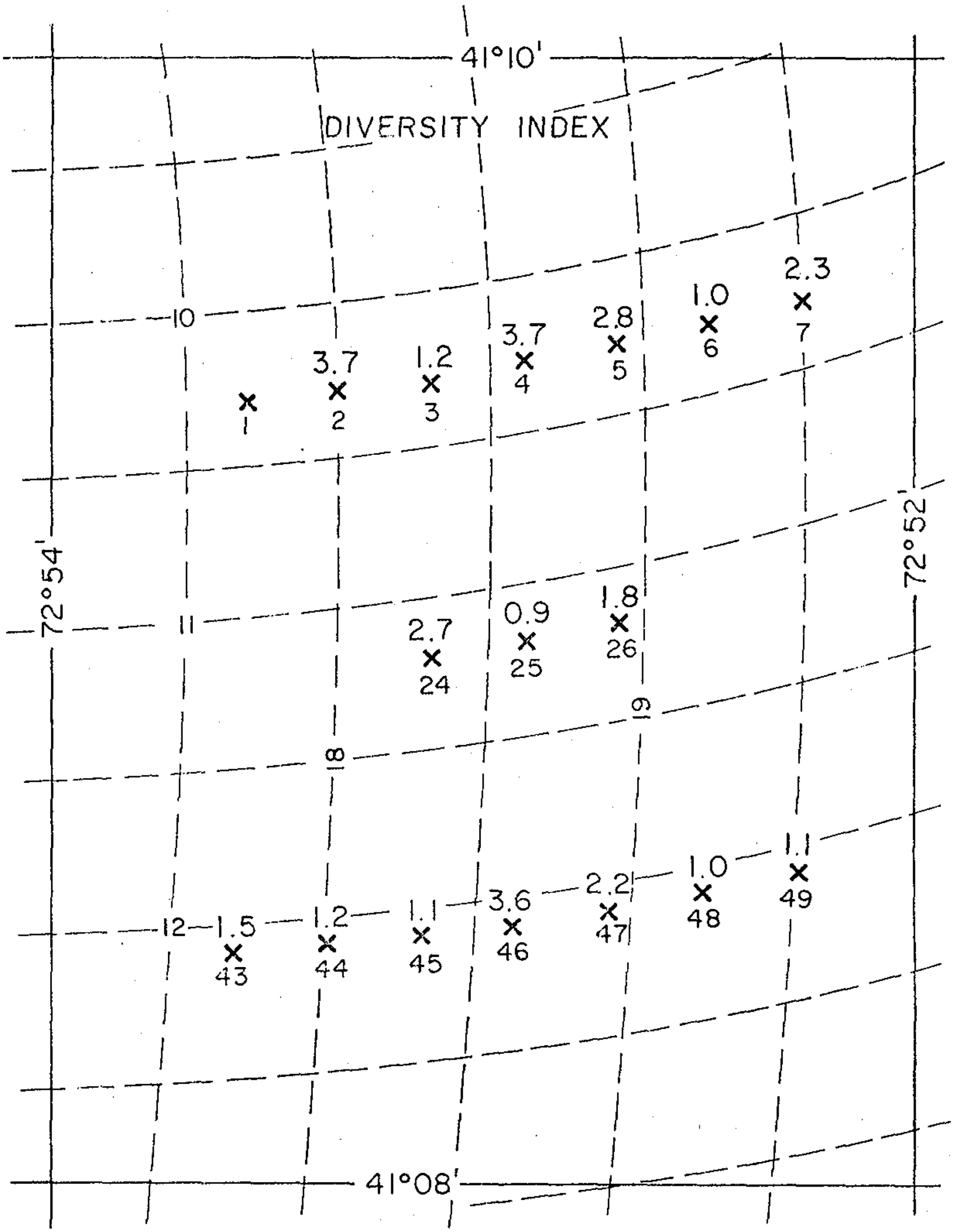
The diversity index used in this study is the Brillouin formula for information in bits per individual:

$$H = (1/N)(\log N! - \sum_{1}^{s} N_i!)$$

Sampling Schedule. Thirty-one samples were taken on the dump and southern control sites on July 11, 12, 20, and 27, 1972. Twenty-five samples were recovered from the New Haven Harbor ship channel on July 21 and 28, 1972. Thirty-one samples were taken from the northwest control site on September 4-5, 1972.

Results. Fig. 17 shows the spatial distribution of Brillouin diversity values (H) over the dump site sample grid. The values range from a high of H = 3.76 (Station 4) to a low of H = 0.95 (Station 25). This is a large range of values and probably manifests an underlying heterogeneity in the

Figure 17. Brillouin diversity index values at biological sampling stations on the New Haven spoil ground. Dashed lines give range in km from Stratford Point and the Old Tower on Lighthouse Point.



R. Rowen 11/1/72

environment. This patchiness indicates the future requirement for taking small replicate samples rather than a single large (0.16 M^2) sample at each station. Values of $H \geqq 3$ are characteristic of open shelf waters, while values of $H \leqq 3$ are commonly encountered in variable estuarine environments. Values less than one represent very low diversity associations.

The spatial distribution of biomass values also indicates patchiness, i. e. relatively high values are found adjacent to low values (Fig. 18). The range of values is not great, however, considering the large range in number of individuals per station (660-11,800).

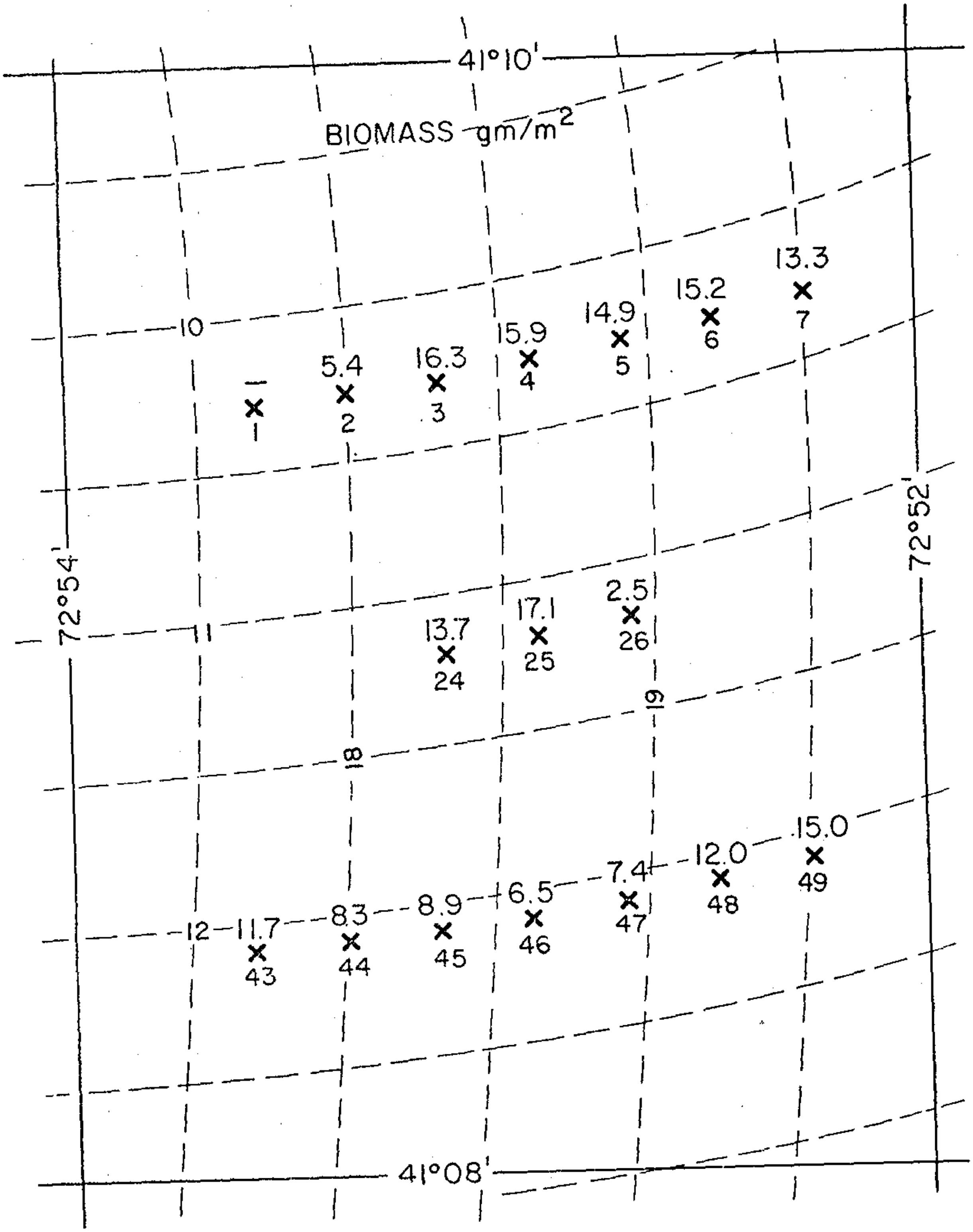
Fig. 19 shows the percentage of species common to station pairs. Approximately 22% of the station pairs share $\geq$ 80% of their species, while 65% of the station pairs share $\geq$ 50% of their species.

Habitat Documentation. One of the most striking physical changes to be expected in a large scale dumping operation is modification of the topography of the seafloor. At the present time, the features observed on the relatively flat mud bottom of Central Long Island Sound are largely biologically produced, i. e. tracks, trails, tubes, burrows, and fecal pellets. In order to evaluate the effects of dumping semiconsolidated mud lumps on the bottom photographic documentation was made of the seafloor in its present state.

Close-up vertical or oblique photographs of the bottom were taken over a small area, by a SCUBA diver using a 35 mm reflex Nikomar camera in an Al Giddings U/W housing. Light was provided with a Strobonar flash unit. Subject to lens distance is about 30 cm.

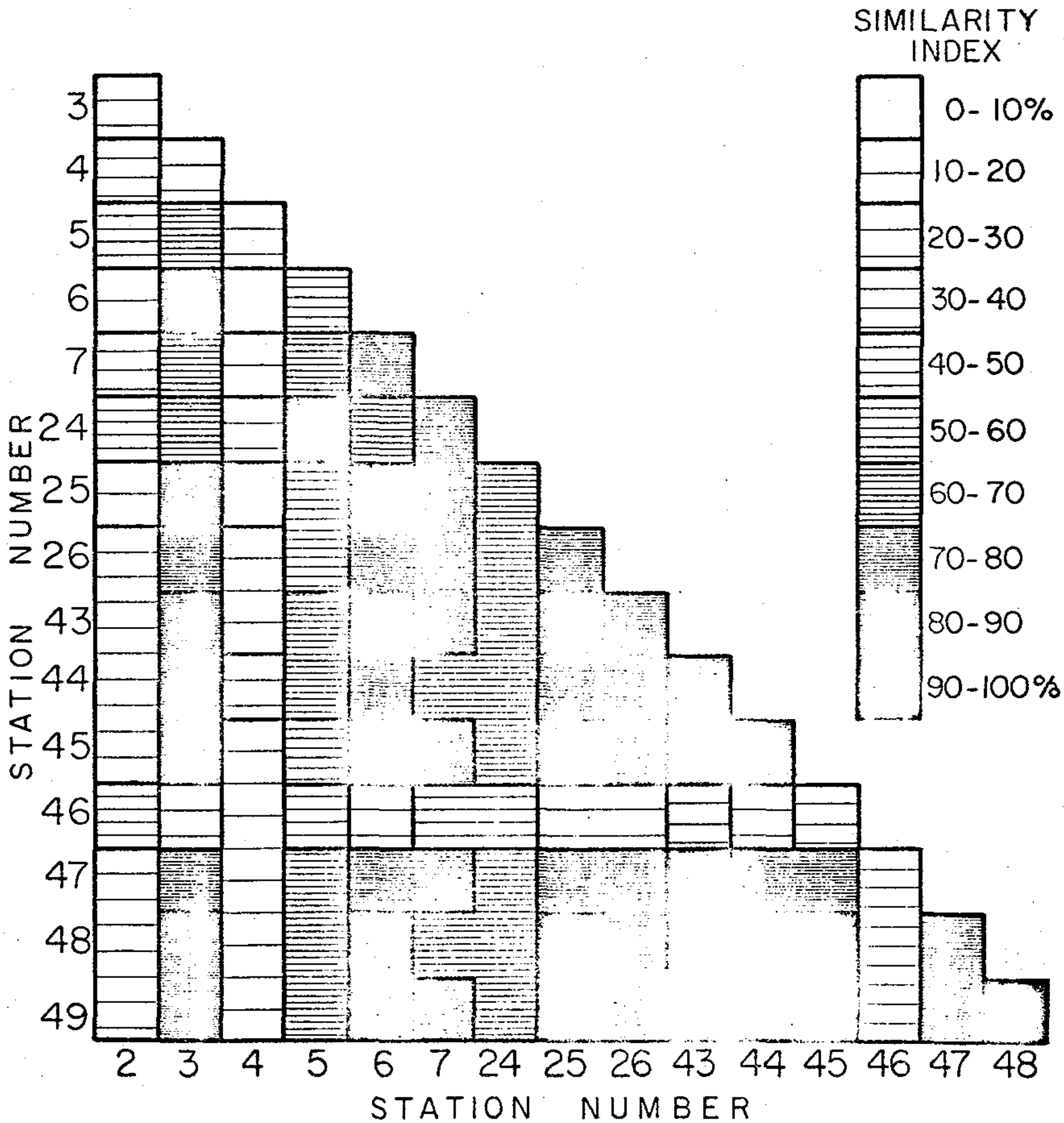
The sediment-profile photographs were taken with a Rhoads-Cande interface camera lowered to the bottom from shipboard. A complete description

Figure 18. Biomass measured on grab samples from the New Haven spoil ground.



R. Reeves 11/1/72

Figure 19. Percentage of species common to station pairs on the New Haven spoil ground.


SIMILARITY INDEX
0- 10%
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100%
STATION NUMBER
3
4
5
6
7
24
25
26
43
44
45
46
47
48
49
2
3
4
5
6
7
24
25
26
43
44
45
46
47
48
STATION NUMBER

of this apparatus is given in Rhoads and Cande (1971) . Fig. 20 diagrammatically shows the camera in position on the seafloor with the "guillotine"-shaped photographic chamber in a lowered position. The vertical cut of the bottom made by this "guillotine" is done very slowly so that disturbance of the structure of the bottom is minimal.

Diver photographs were taken at the dump site and southern control site on 7 July 1972. The dump site was photographed again on 26 September 1972. The northwest control site was also photographed on 26 September 1972.

Sediment profile photographs were taken near the center of the dump site on 27 July 1972. Photography was repeated on 31 August 1972. Profile photographs were also taken at the northwest control site on 31 August 1972.

Results

A. Diver Photographs of the Dump Site: Plates 1-10 (7 July 1972) and Plates 11-13 (26 September 1972) show the following habitat features:

1. The silt clay bottom is covered with evidence of benthic activity such as fecal castings, clam siphon openings, tracks, trails, and burrows.
2. Vagile epibenthos are scavenging decapod crustaceans and the deposit-feeding gastropod *Nassarius trivitatus*.
3. The density of small polychaete tubes is sufficient to bind the sediment (e. g. Plate 6).

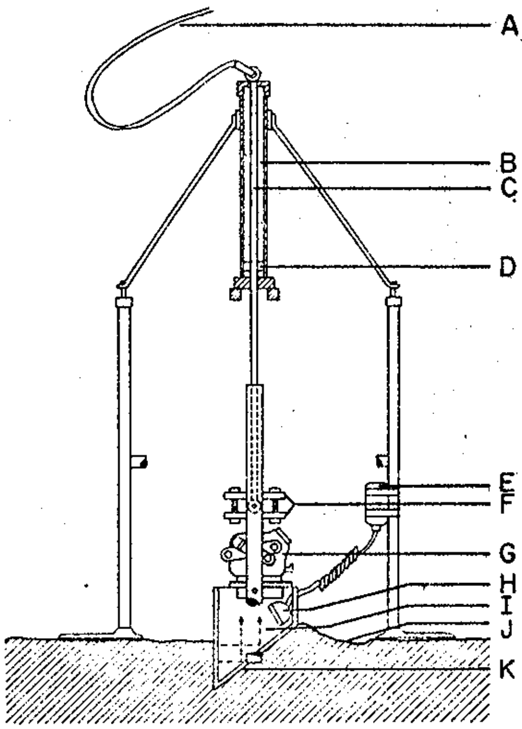


FIG. 20. Schematic drawing of the profile camera in partial cross section showing the cradle in the down position intersecting the bottom. A—slack winch-wire; B—oil-filled cylinder; C—piston rod; D—piston containing a small diameter hole; E—battery housing with magnetic reed switch; F—lead weights; G—camera (oriented vertically); H—light; I—Plexiglas guillotine filled with distilled water; J—sediment-water interface; K—45° angle mirror reflecting the sediment-water interface profile 90° to the camera lens.
(Rhoads and Cande, 1971).

4. Current action is apparent from the linear orientation of small polychaete tubes and sediment streaking (e. g. Plates 6, 7, 8). Current resuspension of the bottom is especially apparent in Plates 11-13 taken during spring tides when bottom turbidity was much higher than when the July photographs were taken.
5. No large mud clasts (dumped mud aggregates) are apparent from these photographs or verbal diver reports.
6. Much dead molluscan shell material is exposed on the seafloor. This records the high birth-death rates of the opportunistic species living on the dump site.
7. The aggregation of fecal castings and gastropods indicates that the environment is "patchy" for some species. The apparent random distribution of Mulinia/Pitar siphon openings suggests that the environment is homogeneous for these species.

B. Diver Photographs of S. Control Site: Plates 14-20 (7 July 1972) show the following features:

1. The surface is covered with evidence of biogenic activity like the dump site.
2. The S. control area shows evidence that some dumping may have occurred here. The bottom topography shows small scale relief and mud clasts (e. g. Plate 14).
3. Bottom current activity is apparent in almost every photograph. This bottom obviously undergoes at least periodic erosion. Although binding polychaete tubes are present (Plate 17) their density may be insufficient to retard erosion.
4. Broken worm tubes and dead shell debris are common on the surface.

C. Diver Photographs of N-W Control Site: Plates 21-24 (26 September 1972) show the following features:

1. The surface is covered with mobile granular fecal-pellets.
2. Dense mats of tubicolous polychaetes are lacking.
3. Current lineation and erosion are apparent from sediment streaking, tube alignment, and scour around dead bivalve shells.

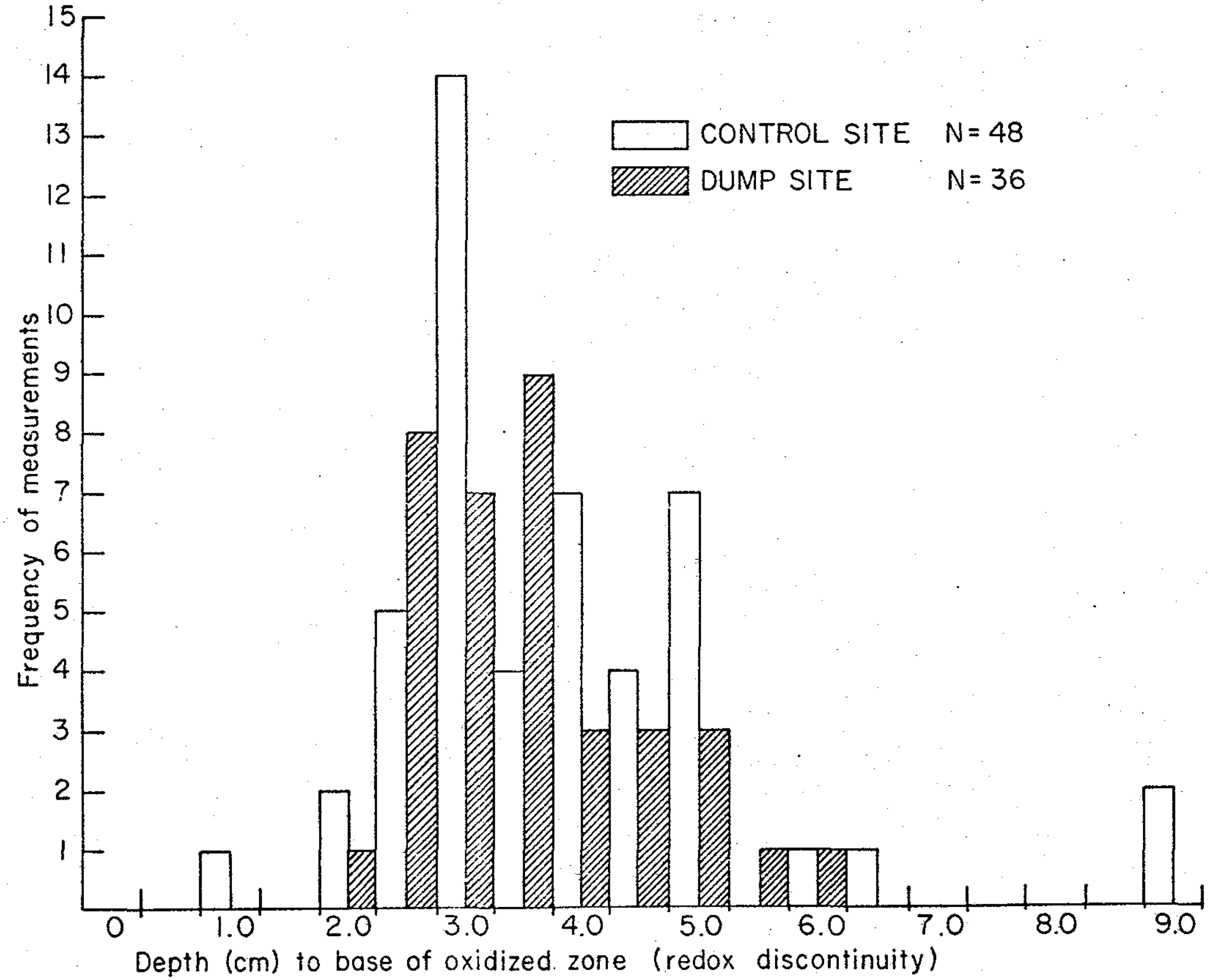
D. Sediment Profile Photographs of the N-W Control Site: Plates 25-29 show the following features:

1. The depth of the redox discontinuity averages $\simeq$ 3 cm (Fig. 21). The depth of oxygen penetration into a mud bottom devoid of large burrowing organisms is $\simeq$ 1-2 mm. The cycling of oxidized sediment from the bottom surface to a depth of 3 cm is therefore caused solely by burrowing activity. Laboratory experiments have indicated that a minimum turnover rate of about 4 days is required to maintain this equilibrium of oxidation-reduction balance at a 3 cm depth (at $\sim$ 20°C).
2. A thin fecal pellet zone (about 1 cm thick) is present at the sediment surface. It is this pellet zone which is resuspended causing high bottom turbidity.
3. The reduced sediment below the redox discontinuity appears uniformly reducing, i. e. same contrast.

E. Sediment Profile Photographs of the Dump Site: Plates 30-33 (31 August 1972) show the following features:

1. The depth of the redox discontinuity is about 3.0-3.5 cm (Fig. 21). This represents a minimum turnover rate of about 4 days at 20°C.

Figure 21. Depth of the oxidized zone of surface sediment as determined from interface photographs on the dump site and the NW control site.



CONTROL SITE N= 48
DUMP SITE N= 36
Frequency of measurements
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
Depth (cm) to base of oxidized zone (redox discontinuity)

2. The surface is covered with a 1-2 cm deep layer of fecal pellets.
3. The reduced sediment is variable in contrast suggesting layering of mud of different organic content. This may be unique to the dump site related to dumping and differential settling of fines rich in organic content.

Further evidence on the bottom habitat is obtained by radiographic examination of cores collected on the NW control site. The radiographs show discontinuities in the upper half meter of sediment occurring roughly at about 10 cm intervals. These are tentatively identified as bottom scour produced by major storm events. Since the sedimentation rate on this site is thought to be about 3 mm/year, these major storms evidently occur about every thirty years or so.

GEOCHEMISTRY OF LONG ISLAND SOUND AND NEW HAVEN HARBOR SEDIMENTS AND ORGANISMS

Introduction. The aim of the geochemical program is to assay the chemical quality of the dredge spoil material, especially with regard to the metals, and explore the degree to which these chemical effects are recorded in the organisms common to the area. Any inferences regarding the influence of the specific chemical environment typical of metal polluted sediments cannot be drawn directly from such a study. Rather the presumption is that if the variations in the composition of organisms cannot be coupled to the chemistry of the substrate, it may be assumed that a direct effect of the substrate chemistry can be eliminated for the species extant in the area.

This does not rule out the role of gross changes in the chemistry of the environment. In particular the pH and oxidation-reduction potential as well as fouling particulates and toxic organic compounds might be the prime control on species survival in a particular region.

In our study we have concentrated on the composition of the soft tissue of organisms. Sediment composition was assayed through the U.S. Corps of Engineers' laboratories. As we had made an extensive independent chemical survey of major parts of New Haven Harbor in an early study (Turekian *et al.*, 1972) we were able to compare our results with the analyses supplied to us. We found the comparison quite good and thus sensed that further analysis of the sediment was not called for.

Analytical Procedure. Samples, separated by genus and site, were kept on filter paper in sealed glass jars. About 50 of the largest samples were analyzed by the following procedure. Covers were removed and intact samples placed in a drying oven overnight at 110°C. The dried material was carefully transferred from filter paper into nitric acid washed, pre-weighed, porcelain crucibles and the net weight measured to the nearest 0.01 mg. Dry weights ranged from 0.03 to 1.85 g. Prior to ashing at 500-550°C in a muffle furnace, the dried samples were moistened with a few drops of dilute H_2SO_4 in order to control possible metal volatilization. Several crucibles, less sample, were carried through the procedure as blanks. Upon completion of ashing, the furnace door was opened slightly to allow the temperature to slowly drop below 300°C before removing the crucibles. The ashed samples were stored, until cool, in a dessicator then reweighed to determine weight loss due to ashing. At this point in the procedure, approximately 10 mg of material was separated, sealed, and stored in glass vials for possible further testing. The portion remaining in the crucible was weighed once more before dissolving in 5 ml of dilute (1v conc. HNO_3 : 3v H_2O) acid. The contents of the crucibles were heated via infra-red lamps until almost dry, then about 5 ml more dilute nitric acid was added before transferring to the filter funnel equipped with low ash (Whatman 41) filter paper. The crucible and contents were rinsed three times with small portions of acidified, deionized, distilled water until a total volume of exactly 10 ml had been collected and stored in stoppered vials.

Concentrated atomic absorption standard solutions of Zn and Cu (as nitrates) were diluted stepwise using 1N HNO_3 to final concentrations of

0.2, 0.5, 1.0, 2.0, 5.0 and 10.0 μg/L of mixed Cu and Zn, using large volume (25 to 100 ml) transfer pipettes.

Samples were analyzed immediately for Cu and Zn using a Perkin-Elmer Model 303 atomic absorption spectrophotometer equipped with a 4 inch single-slot burner adjusted to give a feathery blue flame on air-acetylene fuel. Operating conditions are given below:

Element	Nominal Wave Length	Slit	Range	Lamp Current	Air		Fuel	
	mμ			ma	Pres.	Flow	Pres.	Flow
Cu	325	4	UV	15	23	9	8	8
Zn	214	5	UV	15	23	9	8	8

Sample % absorption was recorded at either 1X or 3X basic sensitivity at 0.75 in/min chart speed. A number of samples required further dilution to bring their concentration onto the linear portion of the response curve. Standards were run at frequent intervals.

Concentrations were read from calibration curves constructed from the height of the flat-topped absorption signals over baseline and, with appropriate dilution factors and sensitivities, used to calculate sample concentration on dry and ash weight bases. Blank values, significant only for Zn, were used to correct the concentrations reported in units of μg element/g sample (ppm).

Results. The results on the organisms we analyzed for copper and zinc are presented in Table 10. We list the concentrations both on the dry and the ashed basis. Table 11 lists the analyses on the basis of species. The results show that there is not a significant difference between the harbor and dump site animals in Cu and Zn content for the two species, Mulinia and Yoldia, common to both locations. There is a significant difference in the metal content of different species, particularly in the case of the anenome.

Table 10

Distribution of Zn and Cu in Soft Tissue of Organisms from

New Haven Harbor Channel and Dump Site in LIS

A. Dump Site

Sample Number	Genus	Wet Wt./Dry Wt.	ppm Zn (Dry Weight Basis)	ppm Cu (Dry Weight Basis)	Zn/Cu
1	*Glycera americana*	8.10	165.	64.0	2.6
1	*Mulinia lateralis*	3.10	6.09	7.37	0.83
1	*Yoldia limatula*	1.64	9.08	11.	0.83
2	Anemone (*Cerianthus*)	16.8	--	96.5	--
2	*Yoldia*	3.21	223.	65.5	3.4
4	Anemone (*Cerianthus*)	4.75	538	118.	4.6
4	*Nucula proxima*	5.05	28.4	49.4	0.58
4	*Pitar morhuana*	2.95	18.7	10.6	1.8
4	Yoldia	4.75	13.5	10.9	1.2
5	Mulinia	2.44	36.5	27.3	1.3
5	Pitar	3.18	31.5	12.4	2.5
6	Mulinia	2.12	26.6	91.7	0.29
6	Yoldia	1.90	37.8	36.9	1.0
7	Yoldia	2.63	45.2	24.7	1.8
15	Mulinia	2.18	19.2	3.33	5.8
15	Pitar	2.49	36.1	9.82	3.7

Table 10, page 2

Sample Number	Genus	Wet Wt. / Dry Wt.	ppm Zn (Dry Weight Basis)	ppm Cu (Dry Weight Basis)	Zn / Cu	
23	Mulinia	4.15	31.0	9.24	3.4	
24	Anemone (*Cerianthus*)	13.6	832.	106.	7.8	
24	Mulinia	2.27	24.5	10.2	2.4	
24	Pitar	2.87	--	12.7	--	
24	Yoldia	2.98	85.	16.9	5.0	
25	Anemone (*Cerianthus*) (6)	14.6	746.	76.1	9.8	
25	Mulinia (1)	2.13	14.7	13.4	1.1	} replicate samples
25	Mulinia (2)	2.02	20.4	13.1	1.6	
25	Pitar (5)	3.97	8.39	14.2	0.59	
25	Yoldia (4)	2.78	16.8	13.3	1.3	
43	Anemone (*Cerianthus*)	12.3	612.	69.0	8.9	
44	Anemone (*Cerianthus*)	15.8	625.	75.7	8.3	
45	Anemone (*Cerianthus*)	8.72	643.	112.	5.7	
45	Mulinia	2.69	28.1	16.2	1.7	
47	Anemone (*Cerianthus*)	6.89	555.	45.3	12.2	
47	Mulinia	2.21	62.8	52.9	1.2	
47	Yoldia	4.44	43.1	13.5	3.2	
48A	Pitar	2.27	22.9	11.9	1.9	
48A	Mulinia	2.61	26.1	12.8	2.0	

Table 10, page 3

Sample Number	Genus	Wet Wt. / Dry Wt.	ppm Zn (Dry Weight Basis)	ppm Cu (Dry Weight Basis)	Zn / Cu
49	Anemone (Cerianthus)	16.4	1140.	140.	8.1
49	Mulinia	2.41	19.0	13.7	1.4
49	Pitar	2.71	31.0	12.6	2.5

B. Harbor

Sample Number	Genus	Wet Wt. / Dry Wt.	ppm Zn	ppm Cu	Zn / Cu
Ke-2	Mulinia	2.74	29.0	18.5	1.6
Ke-15	Mulinia	3.65	24.5	12.4	2.0
Ke-15	Yoldia	3.35	23.1	13.6	1.7
Ke-17	Mulinia	3.07	36.7	17.8	2.1
Ke-18	Yoldia	4.48	62.0	13.7	4.5
Ke-18	Mulinia	3.04	47.3	12.9	3.7
Ke-21	Mulinia	3.62	18.6	35.7	0.52

Notes: "Sample number" refers to the sampling station from which the animals were collected. Numbers 1-49 are from the dump site; numbers Ke-2 through Ke-21 are from New Haven Harbor.

Table 11

Concentrations of Zn and Cu Grouped by Species in the Dump Site and the Harbor

ppm Zn - Dump Site
(Dry Weight)

Sample Number	Mulinia	Yoldia	Cerianthus	Nucula	Pitar
1	6.09	9.08	--	--	--
2	--	223.	--	--	--
4	--	13.5	538.	28.4	18.7
5	36.5	--	--	--	31.5
6	26.6	37.8	--	--	--
7	--	45.2	--	--	--
15	19.2	--	--	--	36.1
23	31.0	--	--	--	--
24	24.5	85.	832.	--	--
25	a. 14.7 b. 20.4	16.8	746.	--	8.39
43	--	--	612.	--	--
44	--	--	625.	--	--
45	28.1	--	643.	--	--
47	62.8	43.1	555.	--	--
48A	26.1	--	--	--	22.9
49	19.0	--	1140.	--	31.0
Average	26.2	57.5	711.	28.4	24.8

ppm Cu - Dump Site
(Dry Weight)

Sample Number	Mulinia	Yoldia	Cerianthus	Nucula	Pitar
1	7.37	11.	--	--	--
2	--	65.5	96.5	--	--
4	--	10.9	118.	49.4	10.6
5	27.3	--	--	--	12.4
6	91.7	36.9	--	--	--
7	--	24.7	--	--	--
15	3.33	--	--	--	9.82
23	9.24	--	--	--	--
24	10.2	16.9	106.	--	12.7
25	a. 13.4 b. 13.1	13.3	76.1		14.2
43	--	--	69.	--	--
44	--	--	75.7	--	--
45	16.2	--	112.	--	--
47	52.9	13.5	45.3	--	--
48A	12.8	--	--	--	11.9
49	13.7	--	140.	--	12.6
Average	22.6	24.1	93.2	49.4	12.0

ppm Zn - Harbor
(Dry Weight)

Sample Number	Mulinia	Yoldia
Ke-2	29.0	--
Ke-15	24.5	23.1
Ke-17	36.7	--
Ke-18	47.3	62.0
Ke-21	18.6	--
Average	31.2	42.6

ppm Cu - Harbor
(Dry Weight)

Sample Number	Mulinia	Yoldia
Ke-2	18.5	--
Ke-15	12.4	13.6
Ke-17	17.8	--
Ke-18	12.9	13.7
Ke-21	35.7	--
Average	19.4	13.7

CONCLUSIONS

The Corps of Engineers specifications for this research request an evaluation of the suitability of the New Haven spoil ground as the site for disposal of approximately 700,000 yds^3 of spoil to be removed from New Haven Harbor; they do not include the examination of other possible disposal sites or theoretical or model studies, which would be required for the prediction of future events at the spoil ground. Because dredging was thought likely to start as early as 15 August 1972, the first objective of this study was, necessarily, the collection of base line data against which future changes at the spoil ground could be evaluated. This is in keeping with the concept of the New Haven Harbor dredging project as an experimental study of the consequences of spoil disposal. Although detailed theoretical and model work has not been done, some preliminary conclusions and projections about this dredging project are possible. A more complete analysis will only be possible when observations have been made during and after the dredge and dump operations.

Harbor Turbidity. A possible source of difficulty during dredging in the harbor is the generation of water turbidity sufficient to be damaging to resident animals. Turbidity observations made while dredging is in progress will give the best indication as to whether or not this is a problem. However, an argument which puts the turbidity problem in better perspective can be made along the following lines. Suppose that the dredge bucket lifts 10 m^3 of silt per minute and that 1% of this is lost into the water. Suppose that a tidal stream flows at 50 cm/sec past the dredge site. In New Haven

Harbor this stream will flow approximately parallel to the channel. The dredge is, therefore, a source which continuously generates turbidity in the amount of 0.1 m^3 of sediment over an area of 30 m^2. If the tidal stream were turned off, a layer of sediment about 3 mm thick along a strip 1 m wide would settle out of it. In fact, there will be lateral dispersion from the stream; the thickness of the settling sediment will be decreased in proportion to the increase in turbid stream width--when 100 m wide, the deposited layer will be only 0.03 mm thick.

The turbidy described above should be compared with that generated by natural causes in the Harbor. Our measurements show that with a force 4 onshore wind (which may be expected about five times a month year round) the optical transmittance in the outer harbor drops to about 60% over a 10 cm optical path because of resuspension of bottom mud. The corresponding suspended sediment concentration is 2.5×10^{-4} by weight or 150 mgm/cm^2 in the water column. This is equivalent to the resuspension of a layer of bottom material 1 mm thick over the whole area of the outer harbor. Bucket dredging is expected to produce turbidity this great only within a few meters of the dredge site; a significant increase in turbidity outside of the channel over that regularly produced by natural causes seems very unlikely.

Spoil Dispersal from the Dump Site. It is proposed to use point dumping so as to concentrate all spoil as near to the center of the designated dump ground as possible. Because of the soft bottom at the spoil ground, all sand-size or large material in the spoil probably will be retained at the place where it is dumped. However, silt and clay size material, unless naturally cohesive and retaining that cohesion through dumping, will be subject to dispersal by the strong tidal stream that runs over the spoil ground. It is estimated from the data in Fig. 2 that at strongest spring tides the water velocity at 180 cm above the bottom will reach 40 cm/sec. During the period between neap and spring tide the resuspended sediment concentration in the water column builds up and the bottom in and around the spoil ground is subject to erosion amounting to about 0.5 mm. During the following spring to neap period deposition occurs. But there is a net, non-tidal water flow over the spoil ground of about 1.5 cm/sec (1.3 km/day) to the NW: Sediment eroded at the spoil ground will be deposited to the NW while fresh sediment from the SE is brought into the spoil area and deposited. A northwesterly transport of silt and clay, diminishing towards shore as the tidal streams weaken, is expected for this region. (When all of the current meter data are reduced a better estimate of the path of this material will be made.)

A quantitative calculation of spoil dispersal by this process should be made. It will be necessary to know the degree of cohesion of the dumped spoil, the rate at which benthic animals mix the upper layers of sediment, and the amount of sediment exchange between water "saturated" with suspended sediment and the bottom. We offer the following estimate: Cohesion of the dumped spoil will be small (because of its high water content), benthic organisms will turn over (mix) the bottom in less than 2 weeks, and exchange will not be of major importance. Then, each month, a 1 mm thick layer of spoil will be transported 10 km to the NW. After a few years only the sand part of the spoil will remain at the dump site; the silt and clay fractions will be dispersed over a wide area to the NW of the dump site.

At this time it appears that dispersion of spoil from the dump site by storms will be small compared to that due to tidal streams. For waves to significantly increase the amount of resuspended sediment at the spoil ground, the maximum horizontal water particle velocity at the bottom due to waves would have to exceed about 5 cm/sec. From small amplitude wave theory it is estimated that the required sea state would be one of waves 10 ft high and about 100 ft long. A force 7 wind would have to blow continuously for about 5 hours from the E, SE or SW to raise such a sea. Storms of the requisite magnitude will be rare events. Major disturbance of the bottom will probably occur only once every 30 to 50 years.

<u>Benthic Habitat and Biology</u>. Photographs show that the dump and S. control sites are similar physical habitats and show evidence of benthic disturbance. Evidence of benthic biologic activity at both sites is great. Both environments show evidence of patchiness. Current activity is apparent and erosion has taken place. The high density of binding polychaete tubes on the dump site may be significant in stabilizing the bottom and trapping fresh sediment.

The dump site and northwest control sites show differences in surface features. The NW control site surface is flat and almost featureless. The mobile surface layer of fecal pellets prevents the preservation of tracks and trails. The depth of oxygen penetration into the bottom (biogenic turnover) in both the dump and control sites is comparable, indicating that benthic activity is about the same at both sites. (This assumes, however, a similar sediment BOD at each site.)

The data presented here for the New Haven dump site is only meaningful when compared with data from other similar environments or when used for following temporal changes at the same sampling site. Comparison of the dump site with the control and channel areas awaits completion of these samples. For purposes of this initial report, Table 12 has been prepared so that these data may be compared with other similar benthic habitats. Comparable data is available from the Rhode Island Sound dump area. Also included are data from a "pristine" non-dump mud bottom in Cape Cod Bay. Table 12 shows that the New Haven dump site compares favorably with the Rhode Island Sound dump area. Furthermore, the dump areas are not appreciably different from the Cape Cod Bay benthic stations which represent a rather uniform annual salinity-temperature regime. The greater biomass values in Cape Cod Bay are related to the presence of large holothurians. The three sampling areas differ in species composition.

Trace Elements in Sediments. To a first approximation the metal concentration in the sediments of the spoil ground, the south control site and the harbor are all strongly coupled to the organic (or "volatile solids") content of the sediment. We showed this for New Haven Harbor in two earlier reports (Turekian *et al.*, 1972; Turekian and Lewis, 1972) and specifically identified the municipal sewer outfalls as the sources for both the metals and the organic compound in the sediments.

Fig. 22 shows the data for zinc plotted against organic matter for all three sites. It can be seen that although the harbor data form a trend line, not all the samples from the spoil ground and south control sites fall

Table 12

Biologic Comparison of New Haven Dump Site,

Rhode Island Sound Dump Site, and Cape Cod Bay

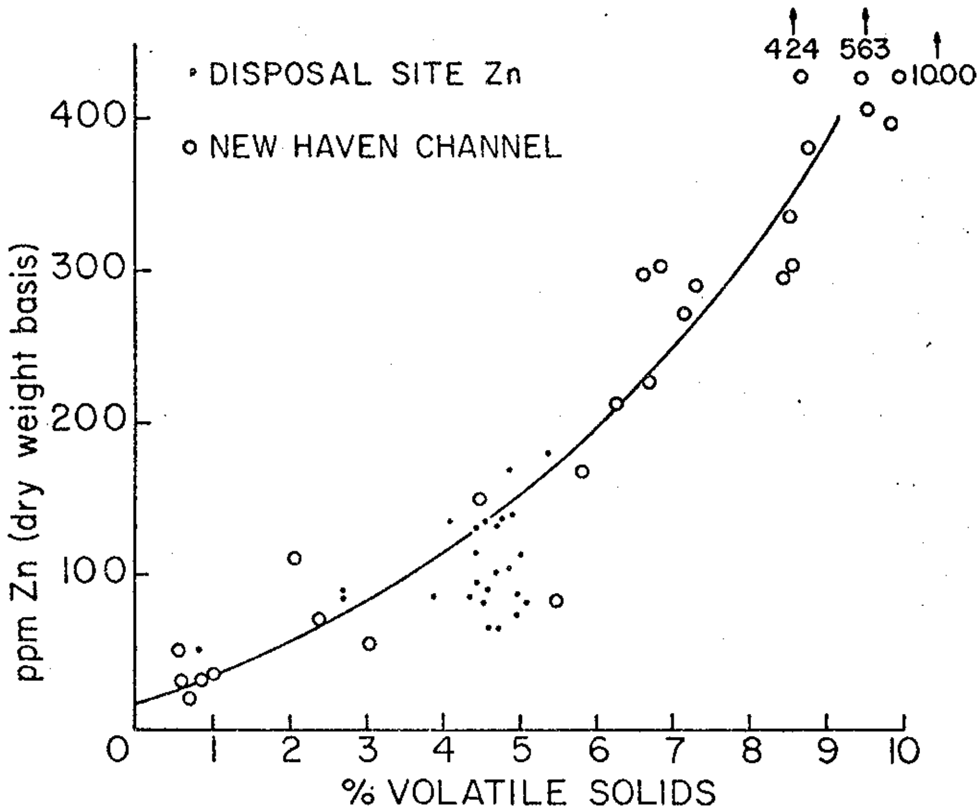
Sample Area	No. Species/0.1 m^2	No. Individuals/0.1 m^2	Biomass - Ash Free Dry Wt. in gm/0.1 m^2	H or H'
New Haven* Dump Site (N = 16)	8-32	660-11,800	0.3-1.7	H = 0.95 - 3.76
Rhode Island** Sound Dump Site (N = 17)	8-53	23-3,275	--	H' = 0.73 - 3.05
Cape Cod Bay*** (N = 4)	34-43	787-1,582	13-38	H = 2.65 - 3.06

* Data from this report

** Saila, S. B., S. D. Pratt, T. T. Polgar, 1972, Dredge spoil disposal in Rhode Island Sound: Marine Tech. Rept. No. 2, Univ. Rhode Island, 48 p.

*** Young, D. K. and D. C. Rhoads, 1971, Animal-sediment relations in Cape Cod Bay, Mass.: A transect study: Mar. Biol., 11:242-254.

Figure 22. Zinc content of sediment plotted against the volatile solids content for samples from the Dump Site and the New Haven Harbor channel.



R. Rowen 11/2/72

on this trend but rather slightly below it, i. e., for a given organic concentration there is a lower zinc concentration. This indicates that metal-poor organic material is being added to the sediment.

The best interpretation of these results is that organic matter formed in sea water is less likely to sequester metals than that formed in soil profiles and sewage sludge. Clear evidence for this is given by Martin (1970) for the Ems estuary where suspended particulates taken progressively seaward show lower zinc concentrations seaward and greater enrichment in carbon-13 relative to carbon-12 (an indication of the substitution of marine produced isotopically heavy organic carbon for land derived, isotopically light organic carbon).

Trace Elements in Organisms. As can be seen in Table 10, only two organisms, *Mulinia* and *Yoldia*, were present in samples both in the harbor and at the test sites.

The averages for copper and zinc for these organisms in the harbor and at the spoil ground site show no significant differences for either of the elements. Obviously the substrate has had no effect on the composition of the soft tissue of these organisms since on the average the harbor sites represented by the samples have sediments twice as high in copper and zinc than the sediments from the test disposal site. Examination of the stomach content of lobsters taken from the dump site shows abundant *Pitar* and *Mulinia*; these animals are evidently an important food for predators. Since excess Zn and Cu in the sediments does not enter *Pitar* and *Mulinia*, we may infer that these elements do not enter lobsters or bottom-feeding fin fish which may be taken at the dump site.

Effects of Past Dumping. A history of past use of the New Haven spoil ground is not available. It was, apparently, last used for disposal of spoil from the 1964 maintenance dredging of New Haven Harbor. The fathometer data in Fig. 16 show that quantities of material far greater than that now to be deposited have been dumped in the area over a considerable period of time. The most recently dumped spoil from New Haven Harbor was probably as badly contaminated as that to be moved in the current dredging.

The benthic fauna now present on the dump site (particularly the abundant *Pitar* and *Mulinia*) are those characteristic of a highly stressed environment. However, until the NW control site samples are worked up, there is no good comparison data, and it is difficult to say whether the stress at the dump site is a consequence of past dumping or is reflecting some natural variability in LIS. Diversity at the dump site is patchy, ranging from very high to very low. The mean value is average for estuaries in general. There has been no long-lasting gross destruction of bottom life on the dump site. The bottom is far from being defaunated and has apparently recovered from the effects of past dumping. In fact, most of the material previously dumped here is now covered by a fresh layer of biologically reworked sediment which has probably been brought in by currents from outside the spoil area.

Suitability of the Dump Site. A fully satisfactory evaluation of the suitability of the designated dump site as a repository for the New Haven Harbor spoil cannot be made because, first, other possible sites have not yet been studied, and, second, there are no generally accepted standards by which to judge suitability. However, the following observations will certainly be an important part of any such evaluation.

There are a number of factors favorable to the use of the designated dump site. They include:

i. Repopulation. Most benthic animals resident at the dump site will be killed by burial. However, repopulation will be rapid because the physical character of the bottom will not be greatly changed for long, and there are abundant neighboring species populations that will act as a genetic reservoir, releasing larvae for recolonizing the dump as well as dredge sites.

ii. Absence of Extinctions. No unique (endemic) species live on the dump site or in LIS. Dumping will not result in the extinction of any species.

iii. Heavy Metal Contamination. Trace metals in the spoil material which enter the gut of benthic animals are not highly concentrated over ambient levels and so are unlikely to enter significantly into the food chain. Trace metal contaminants are associated with the silt and clay fraction of the spoil. This fraction will be dispersed and diluted by tidal stream transport.

iv. Natural Turbidity. The dump site is in an area of high natural turbidity. Except in the immediate vicinity of the dump site, fresh spoil will probably not result in a significant turbidity increase. Resident animals are well adapted to survival under high ambient turbid conditions.

v. Natural Sedimentation. The apparently high natural rate of sedimentation (via resuspension) will cover and rejuvenate the dump area over a period of a relatively few years.

vi. Experimental Site. The site is a favorable one for studying the effect of dumping on benthic animals. The density, biomass, and diversity of the resident population is such that significant changes will be readily detected.

There are also some unfavorable factors:

i. Dispersion. If it be required that a high proportion of the silt-clay fraction of the spoil be retained at the place of dumping, then the site is clearly unsuitable.

ii. Storm Events. The site is susceptible to perturbation by great storms such as may occur once every 30 to 50 years.

iii. Shorewards Transport. Material dispersed from the dump site will probably be carried towards the shore to the NW. It will probably not reach the shore area, but very careful monitoring of this will be required.

At present there is no reason to believe that dispersion and dilution of the silt-clay fraction of the dumped spoil is undesirable. Therefore, there seem to be no major disadvantages to the use of the spoil ground; at this time it appears to be a suitable site for the disposal of the New Haven Harbor spoil provided appropriate monitoring is continued during and after dumping operations.

RECOMMENDATIONS

As already explained, the primary aim of the research reported here has been establish ent of "base-line" data against which future changes can be assessed. A proper evaluation of the consequences of spoil disposal must include theoretical and model studies of processes active in the disposal area.

i. Theoretical and model studies of sediment transport and benthic population dynamics in Central LIS should be carried out.

The best evidence of the consequences of dredging and dumping will come from close observation of actual operations. Certain essential information, such as the turbidity generated by the dredge and the physical properties of the spoil cannot be obtained any other way.

ii. Dredging operations should start as soon as possible. It is particularly desirable that a start be made before the harbor water starts to warm next spring so that the degree of turbidity generated in the harbor can be measured before the oysters become active.

The dredge and dump operations must be closely observed.

iii. The program of physical, chemical, and biological observations at the dump site and its environs already underway must be continued.

Experience has shown the need to enlarge the ongoing program in certain areas.

iv. The presence of hydrocarbons in benthic animal tissue should be measured and compared with that in animals from other localities and in the sediment.

v. The tissues of mobile species, especially commercially important species (lobsters, crabs, demersal fish) should be assayed for hydrocarbons and trace metals.

To allow for the possibility that dispersal of spoil from the designated dump site may prove to be unacceptably high, an evaluation of other possible sites in the Sound should be made.

vi. Chemical, biological and physical studies should be made throughout the whole of Central LIS both to relate the disposal area to its regional setting and to evaluate alternative spoil sites.

ACKNOWLEDGEMENTS

Analysis of much of the geophysical and biological data has been made by Dr. Carol Pilbeam and Dr. Alan Michaels. Instrumental observations on the Sound throughout the study period have been made by Messrs M. Reed and J. Fox. Mr. H. Bokuniewicz computed the fathometer tracks and collected and reduced most of the data on mechanical properties of sediments. SCUBA divers working on the project include Messrs J. Fox, T. Ryer, P. McCall, and J. B. Fisher. The underwater photographs were taken by Mr. W. Sacco.

We received much assistance from Captains Torrey and McGurthy and the crew of the Manamet and from the Corps of Engineers coring and surveying teams who worked aboard this vessel.

Preparation of this report has been facilitated by the continued support of the study by the United Illuminating Company.

Benthic sampling and specimen processing was done by Mr. T. Goreau, Mrs. Margaret Goreau, and Mr. R. Dodge. Margaret Mills provided us with polychaete identifications and assisted us in shipboard processing. Dr. Alan Michael identified the Amphipoda and assisted in directing the biologic program. Mr. W. Sacco took all of the diver photographs.

REFERENCES

Dyer, K. R., Current velocity profiles in a tidal channel, Geophys. Jour. 22, 153 (1970).

Gordon, R. B., Hardness of the sea floor in nearshore waters, Jour. Geophys. Res. 77, 3287 (1972).

Martin, J. M., Contribution a l'Etude des Apports Terrigenes d'Oligoelements Stables et Radioactifs a l'Ocean, Ph.D. Thesis, University of Paris (1971).

Rhoads, D. C., and S. Cande, Sediment profile camera for in situ study of organism-sediment relations, Limnol. Oceanogr. 16, 110-114 (1971).

Riley, G. A., Oceanography of Long Island Sound, 1952-4, II, Physical Oceanography Bull., Bingham Oceanogr. Coll. 15, 345-414 (1956).

Turekian, K. K., Berner, R. A., and Gordon, R. B., Marine sediments, New Haven Harbor, Connecticut: Results of analyses and proposals for dredge spoil disposal, in Addendum 12 of the Environmental Report, Coke Works Site, June 1971, conducted for The United Illuminating Company.

Turekian, K. K., and Lewis, D., Silver, lead and copper in the Quinnipiac River (Connecticut), in Trace elements in natural waters, Annual Progress Report to the Atomic Energy Commission (1972).

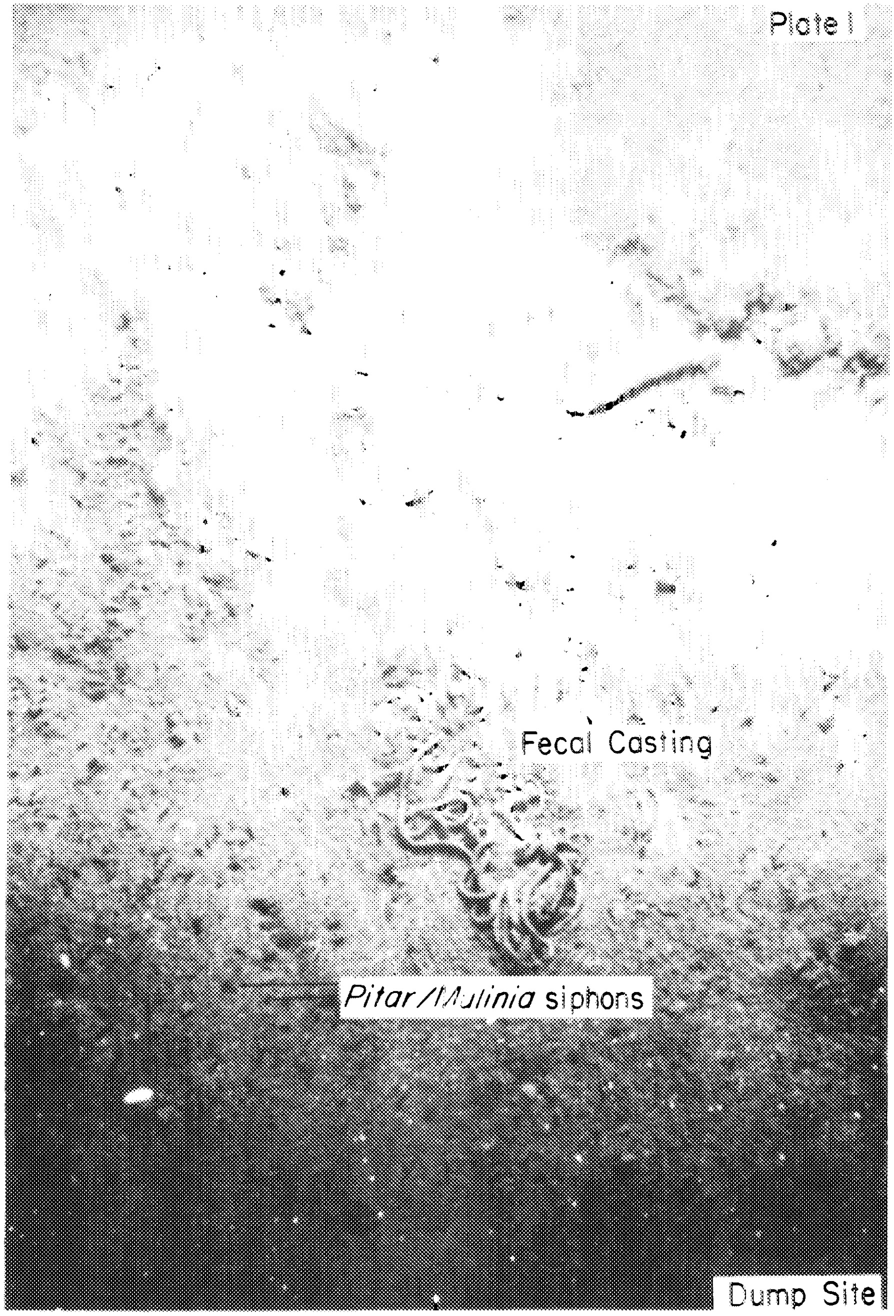


Plate I
Fecal Casting
Pitar/Mulinia siphons
Dump Site

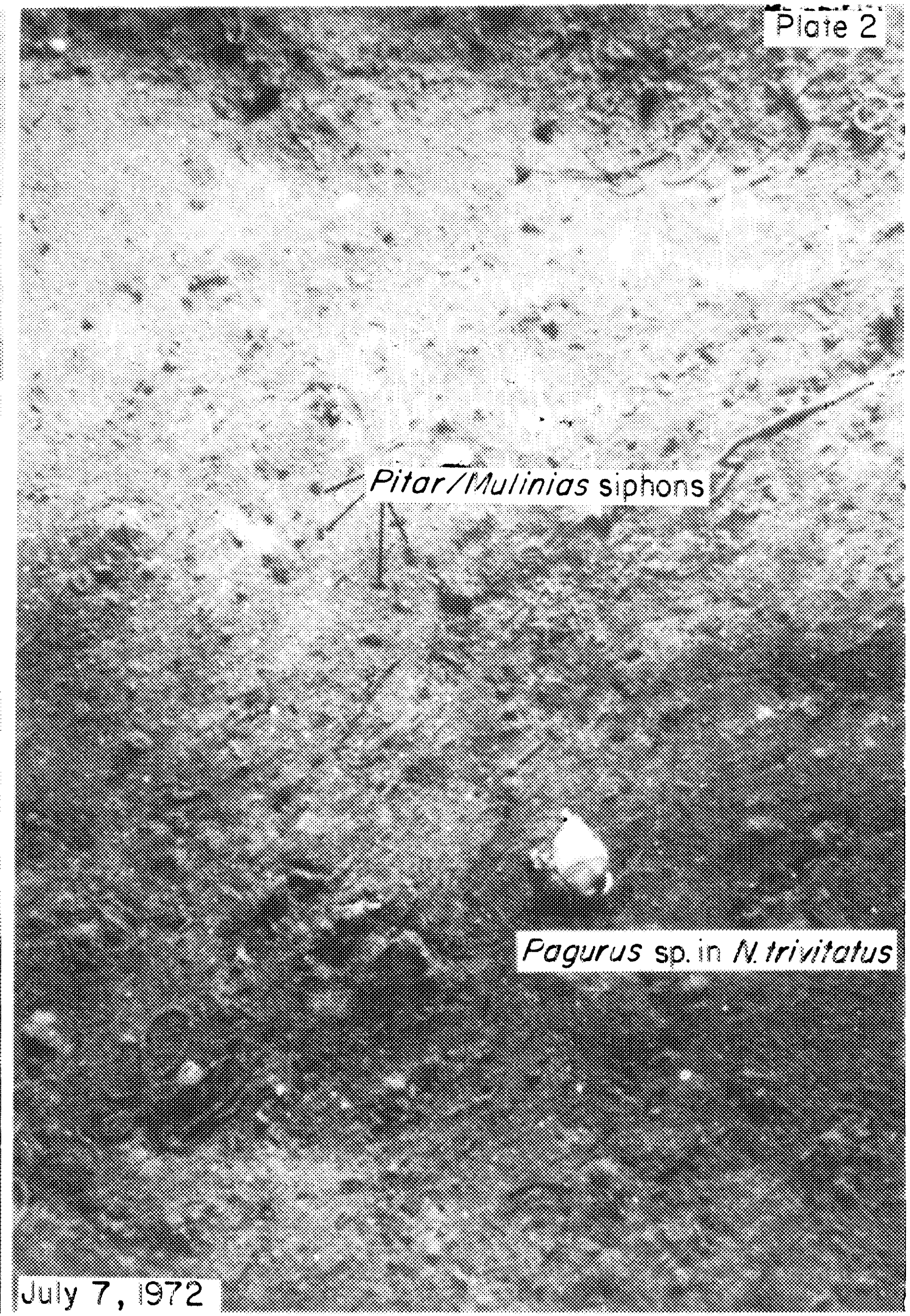


Plate 2
Pitar/Mulinias siphons
Pagurus sp. in *N. trivitatus*
July 7, 1972

Dump Site July 7, 1972

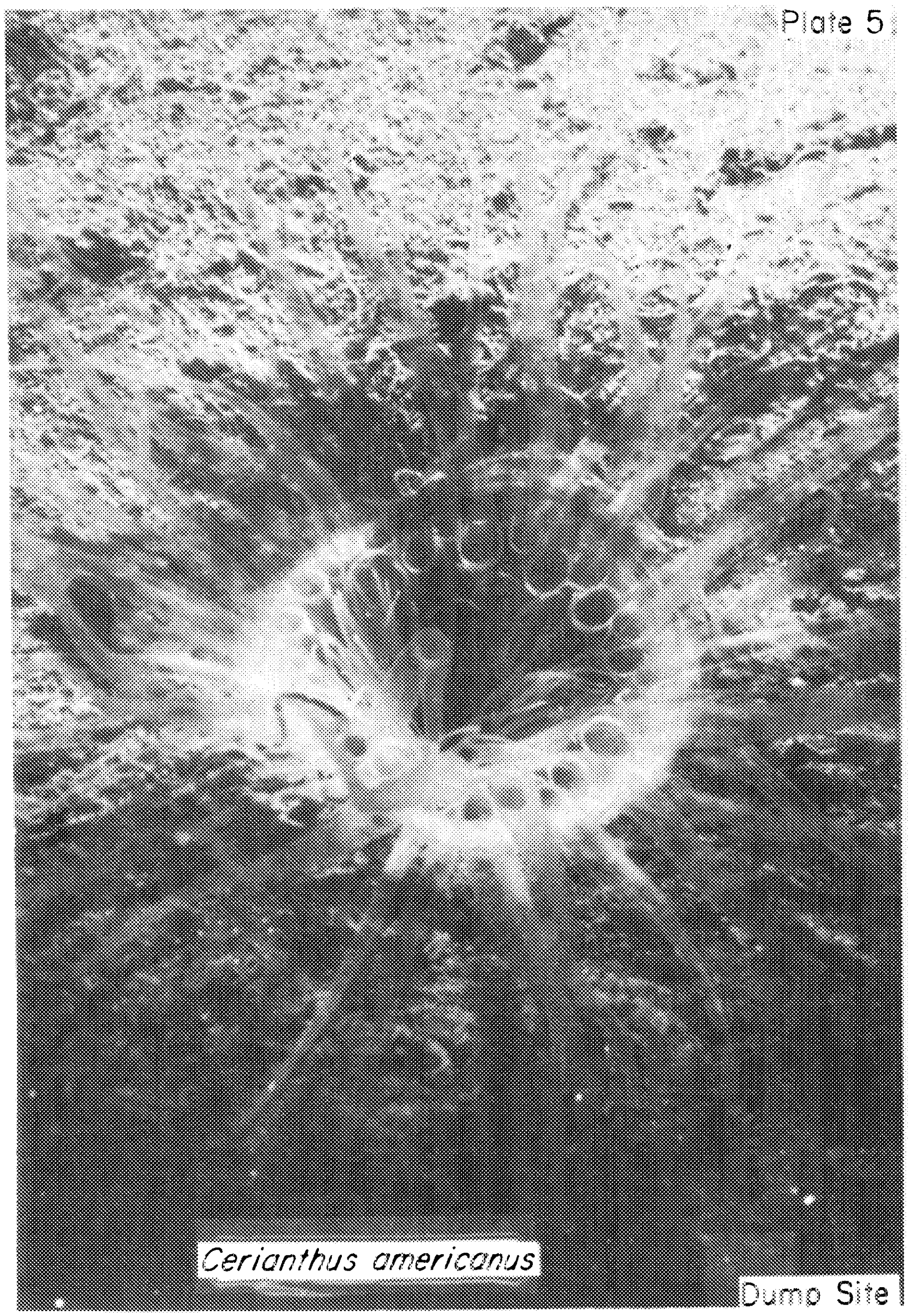


Plate 5
Cerianthus americanus
Dump Site

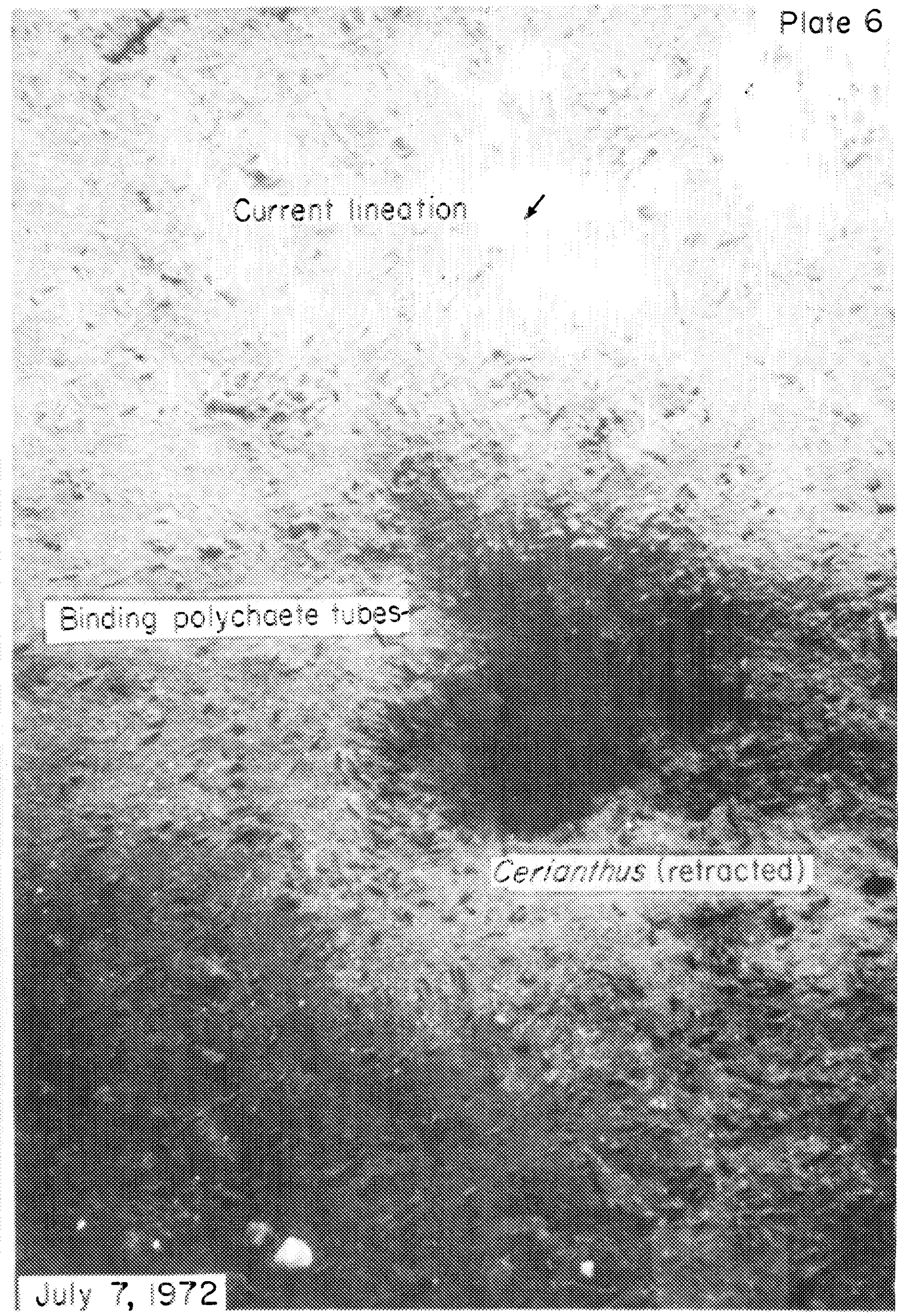


Plate 6
Current lineation
Binding polychaete tubes
Cerianthus (retracted)
July 7, 1972

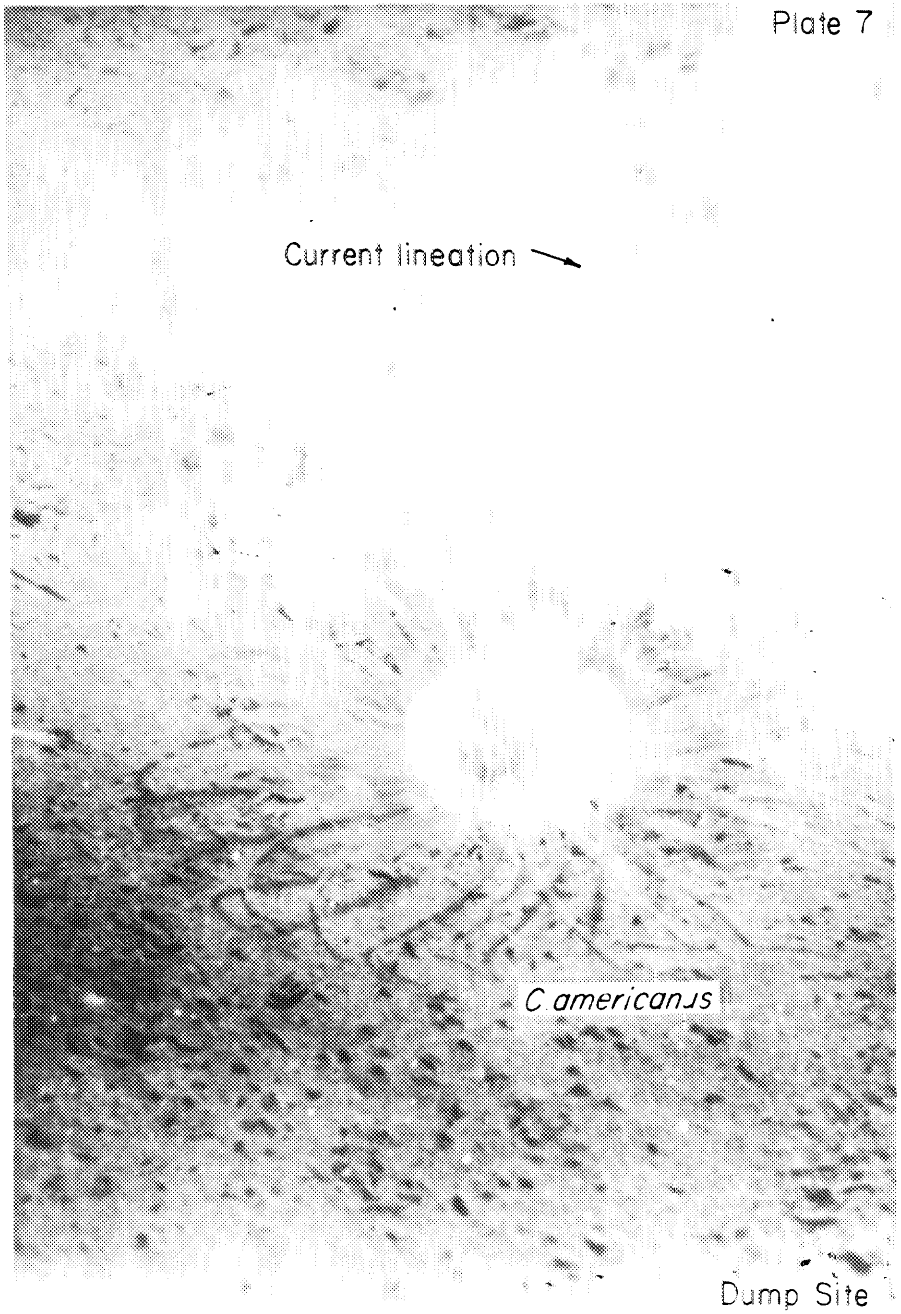


Plate 7

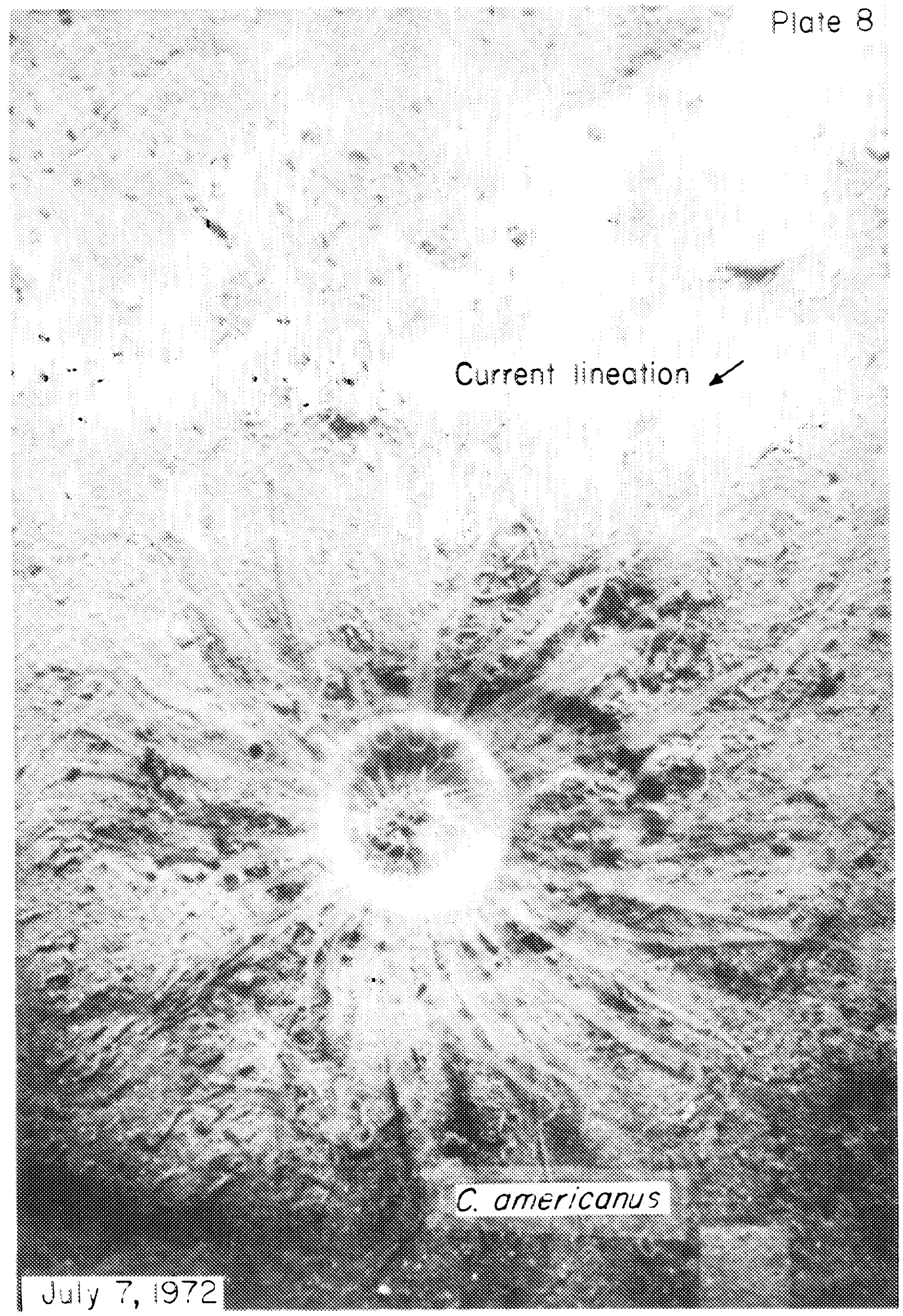


Plate 8

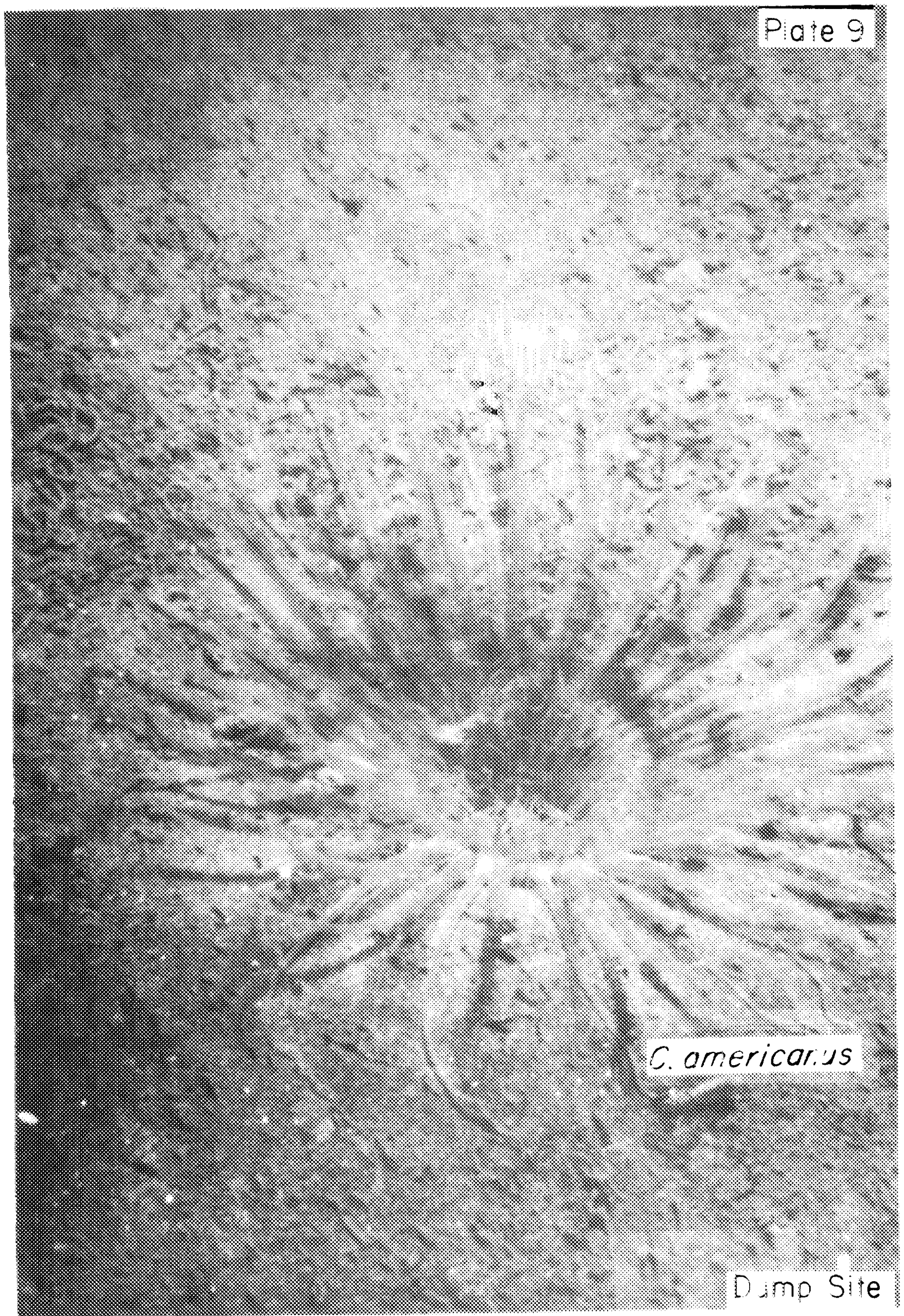


Plate 9

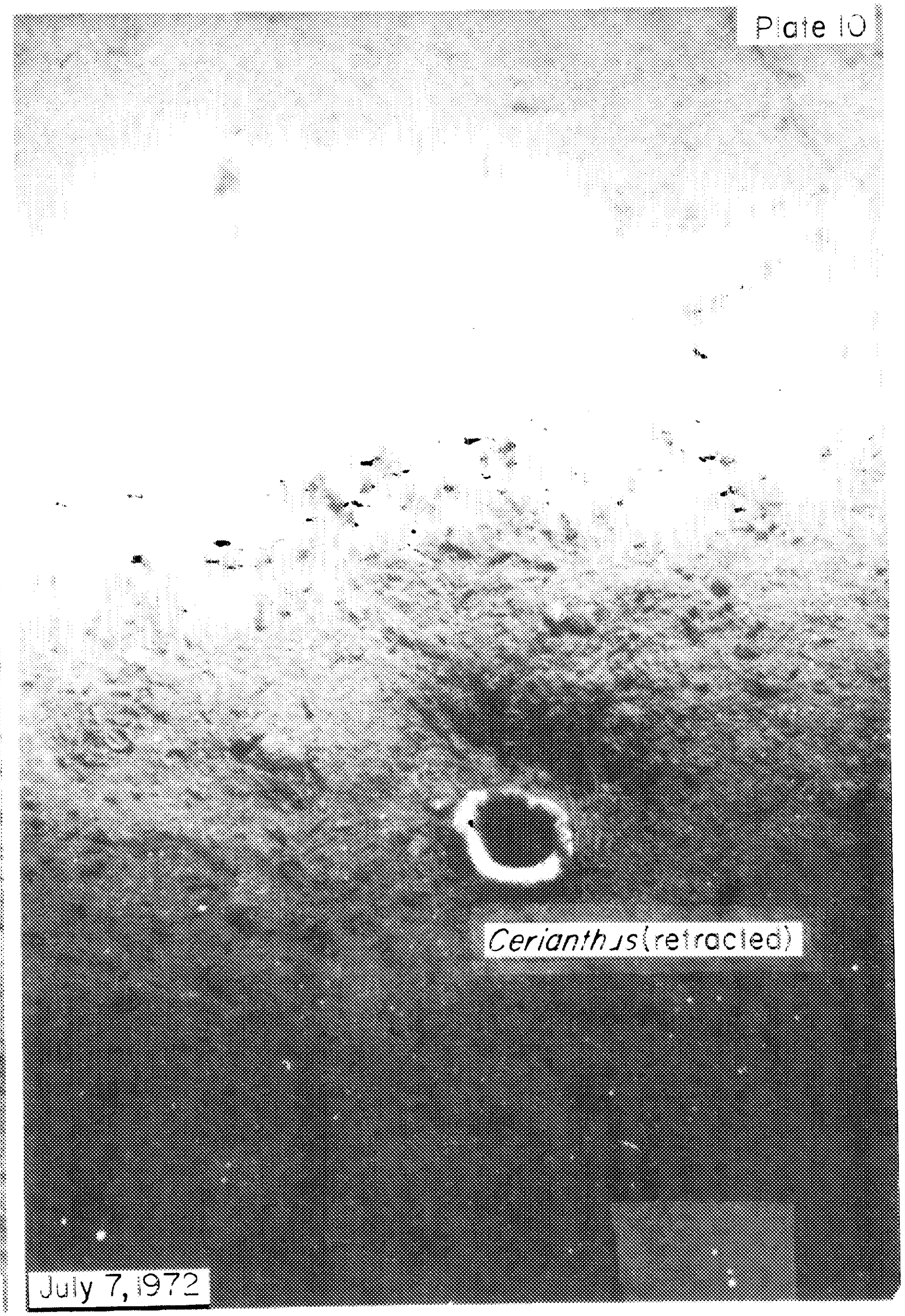


Plate 10

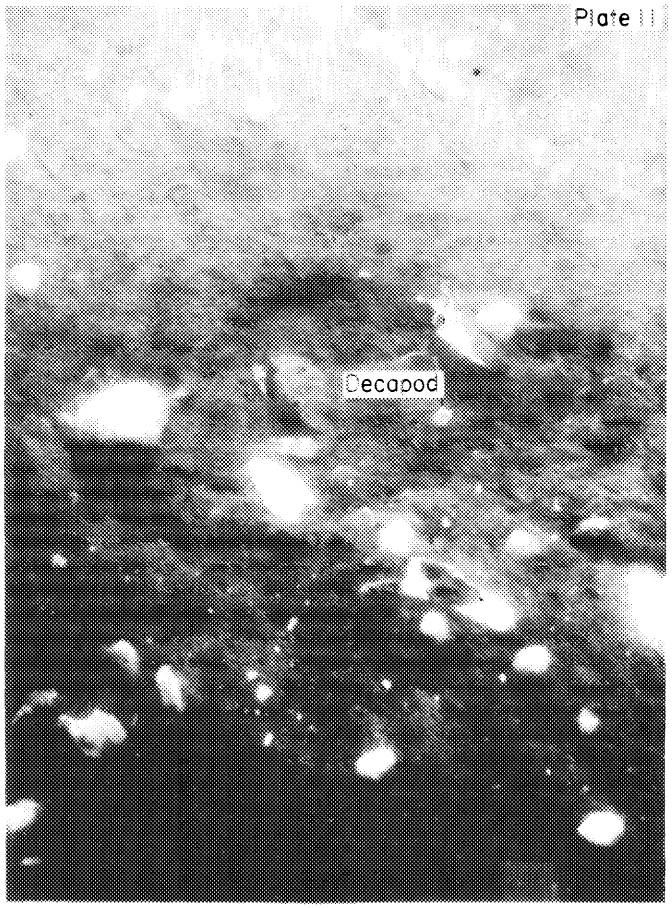


Plate 11
Decapod

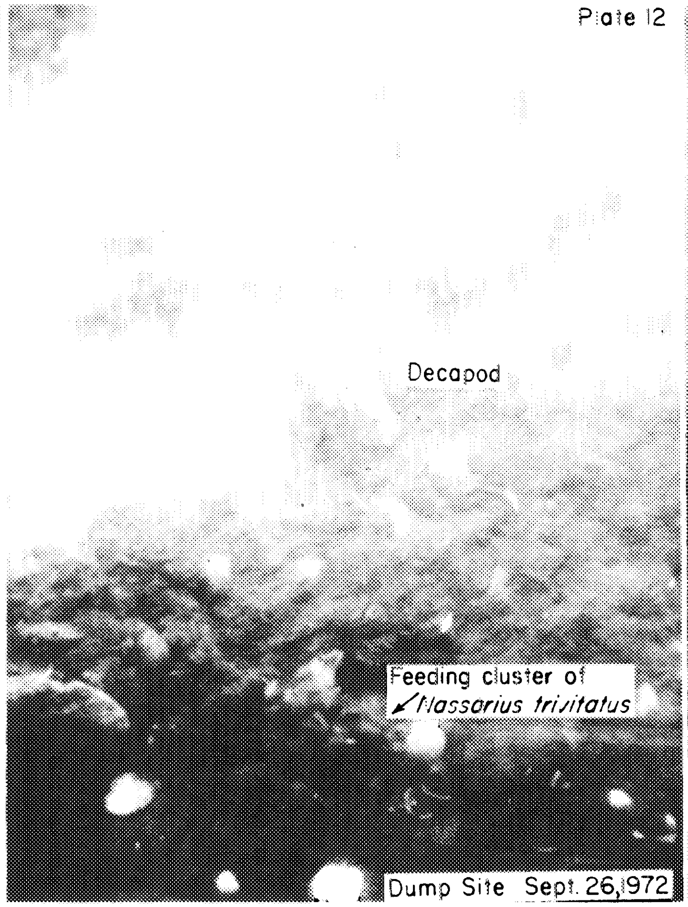


Plate 12
Decapod
Feeding cluster of
Nassarius trivitatus
Dump Site Sept. 26, 1972

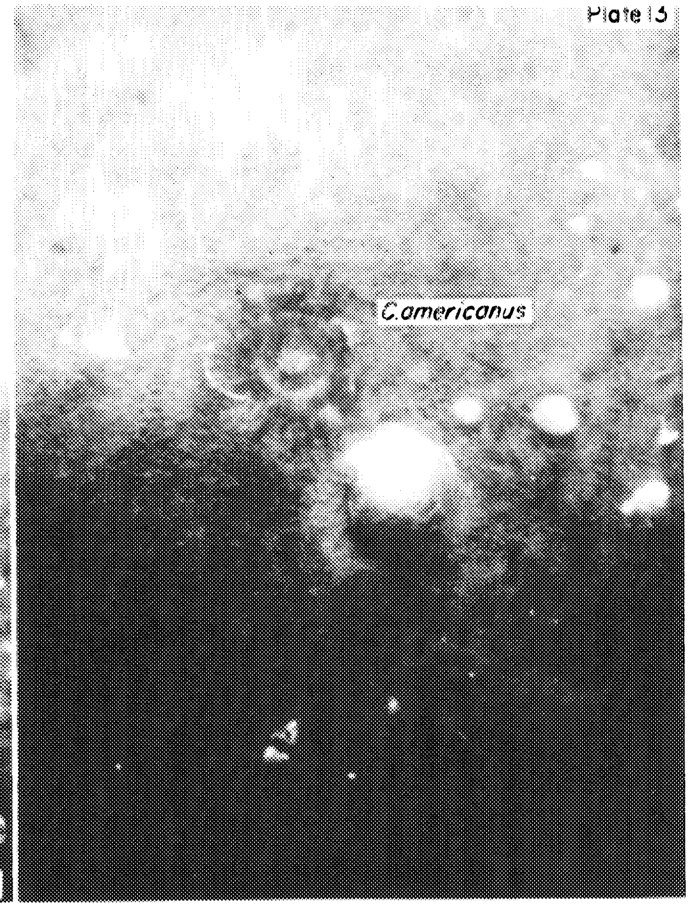
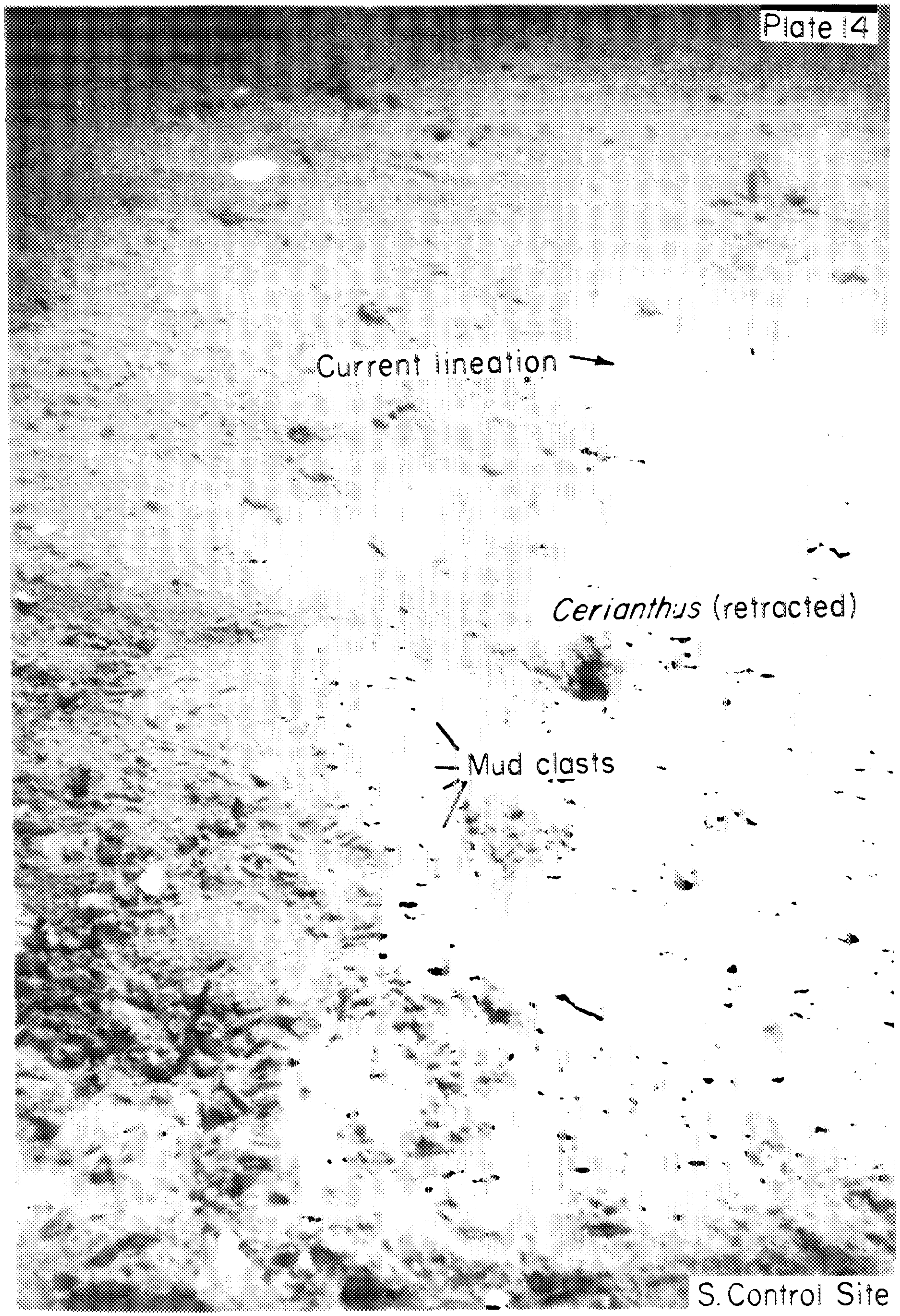
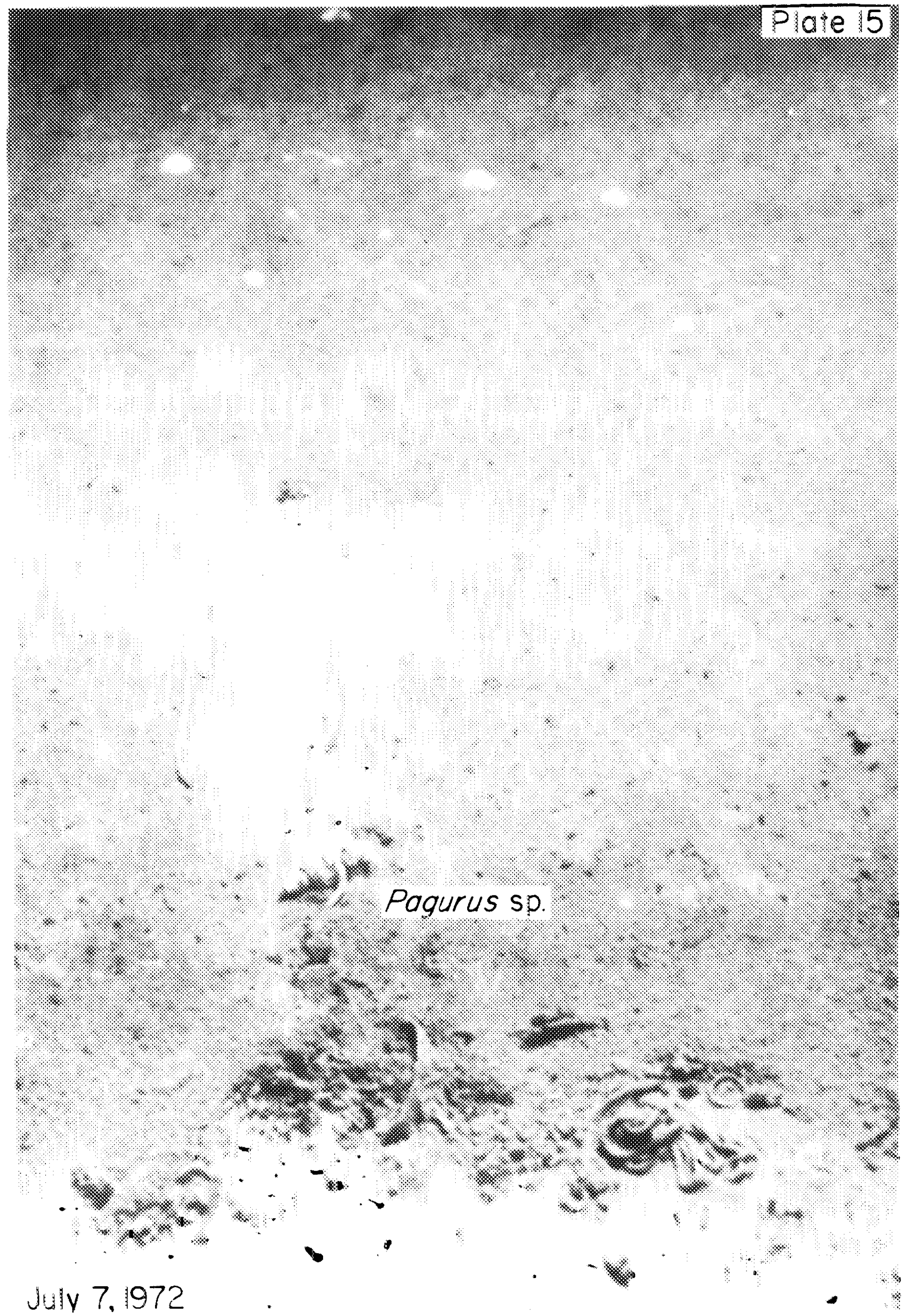
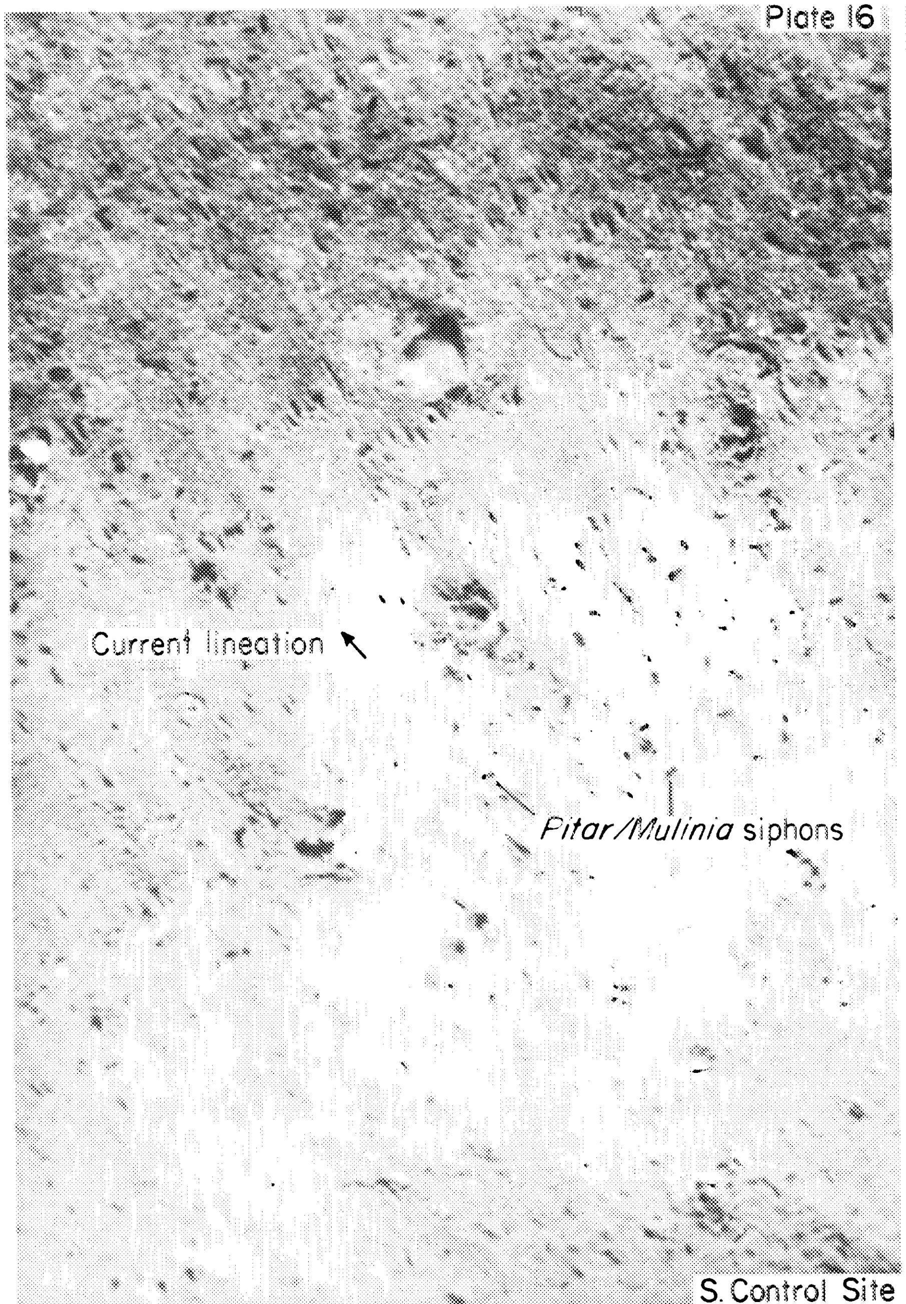


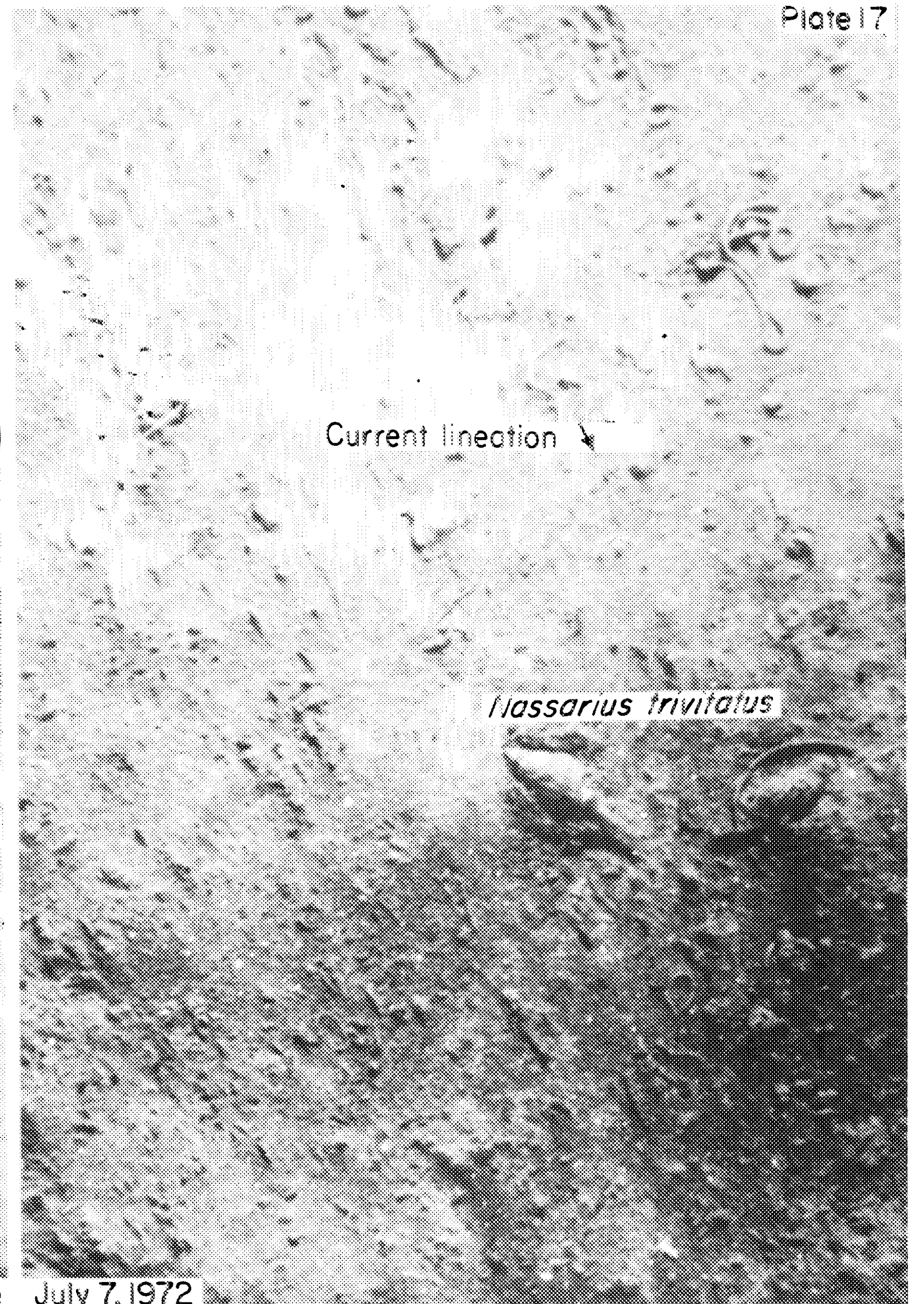
Plate 13
C. americanus



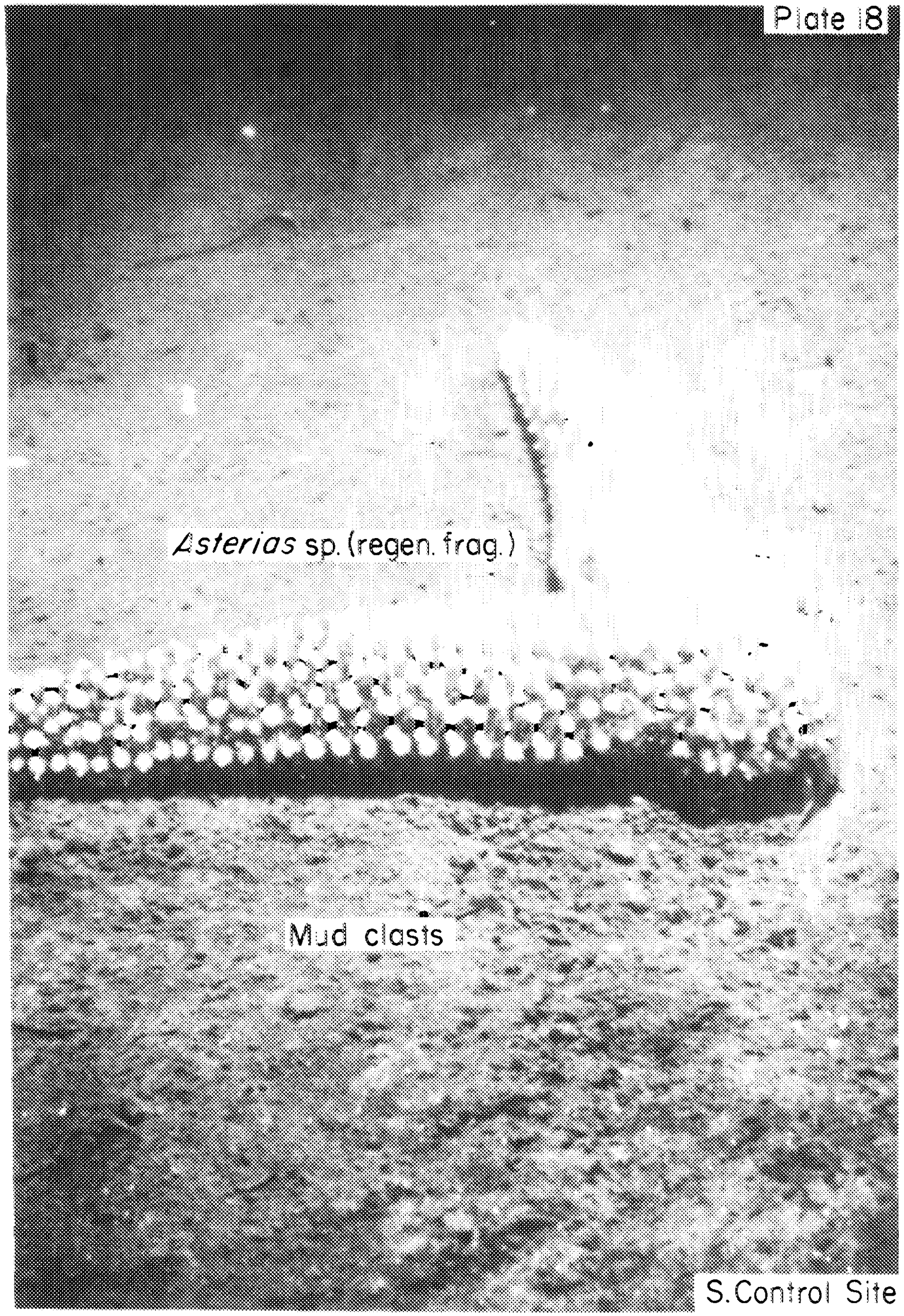


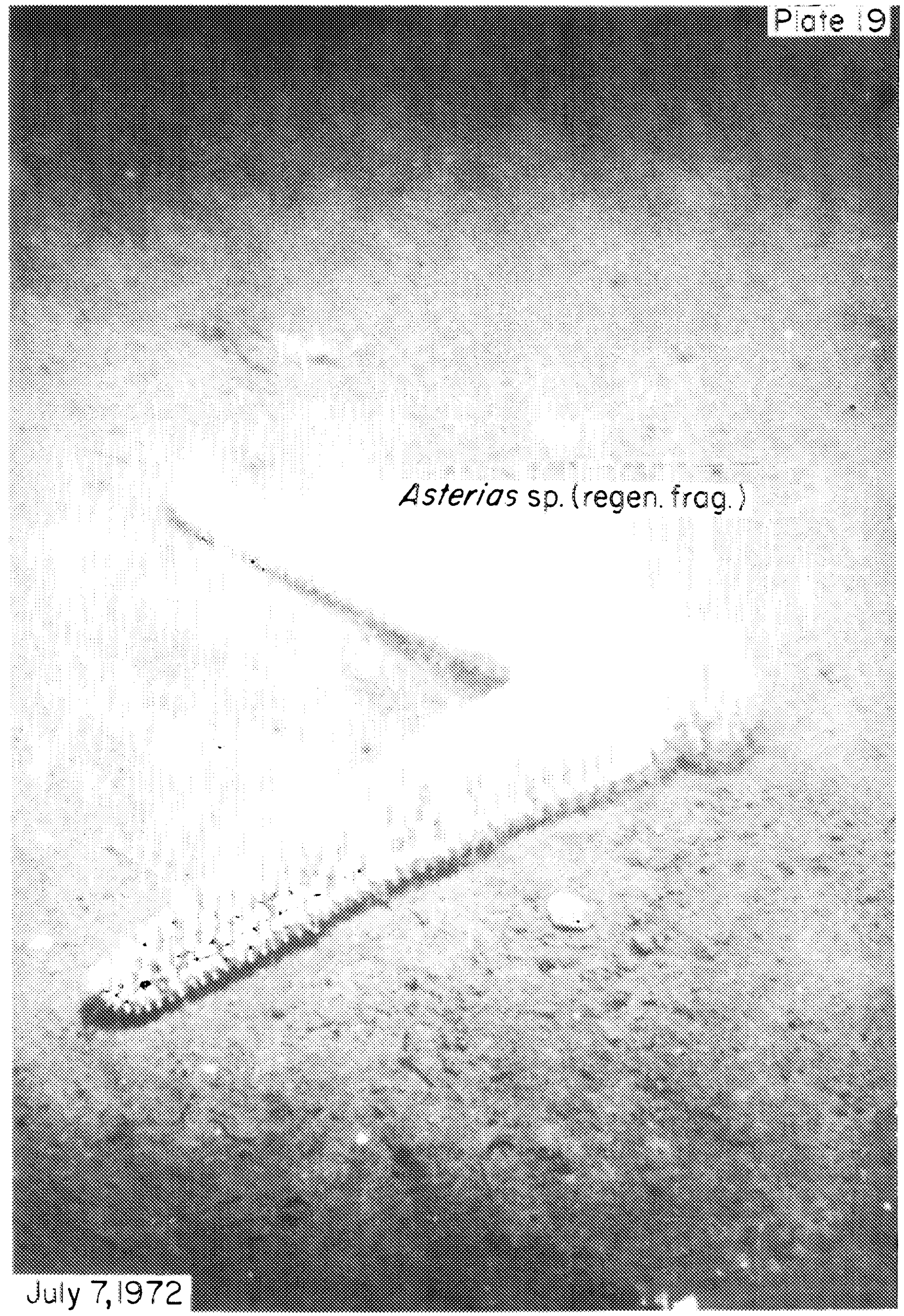
S. Control Site July 7, 1972





S. Control Site July 7, 1972





S. Control Site July 7, 1972

Plate 20

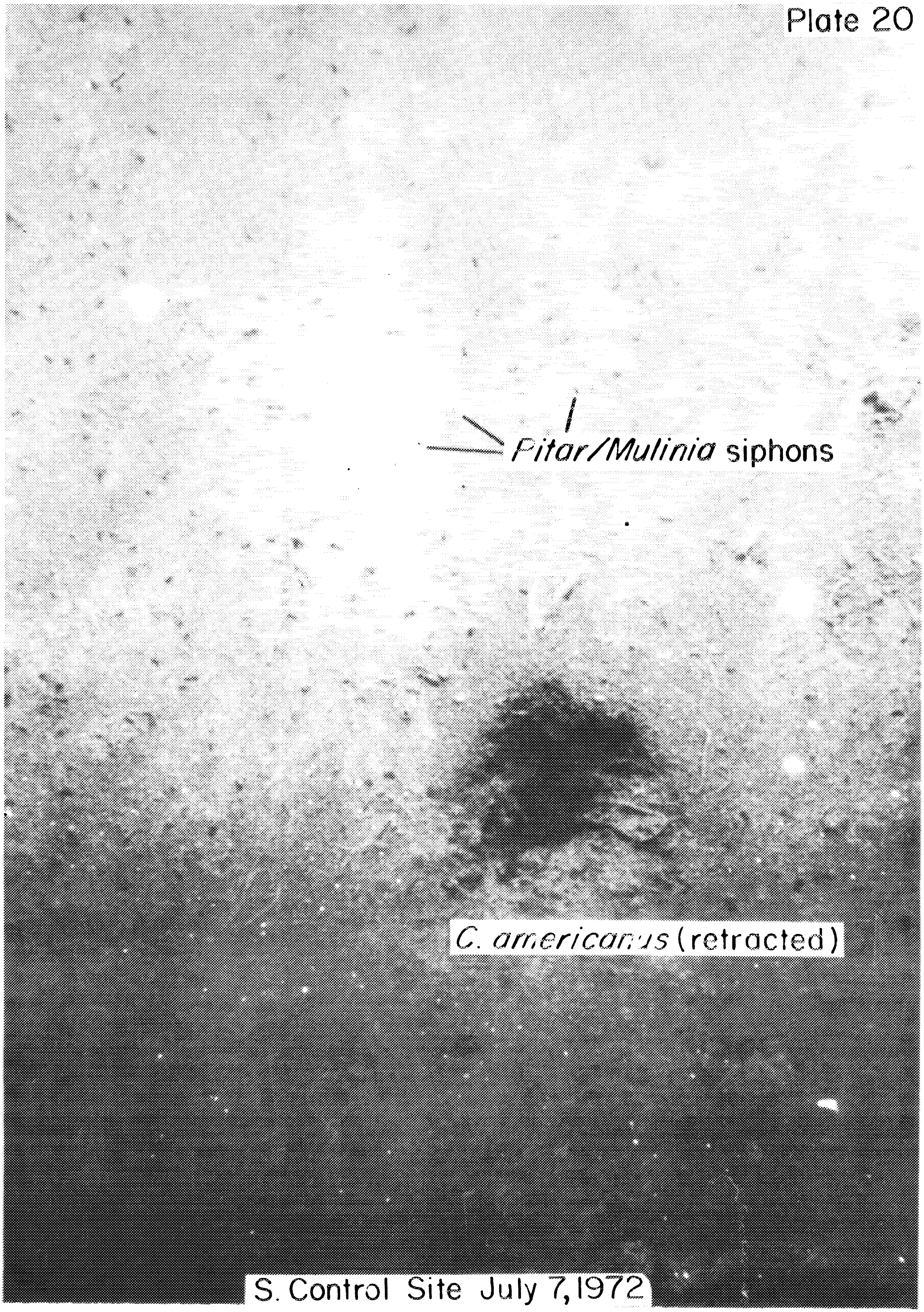

Pitar/Mulinia siphons
C. americanus (retracted)
S. Control Site July 7, 1972

Plate 21

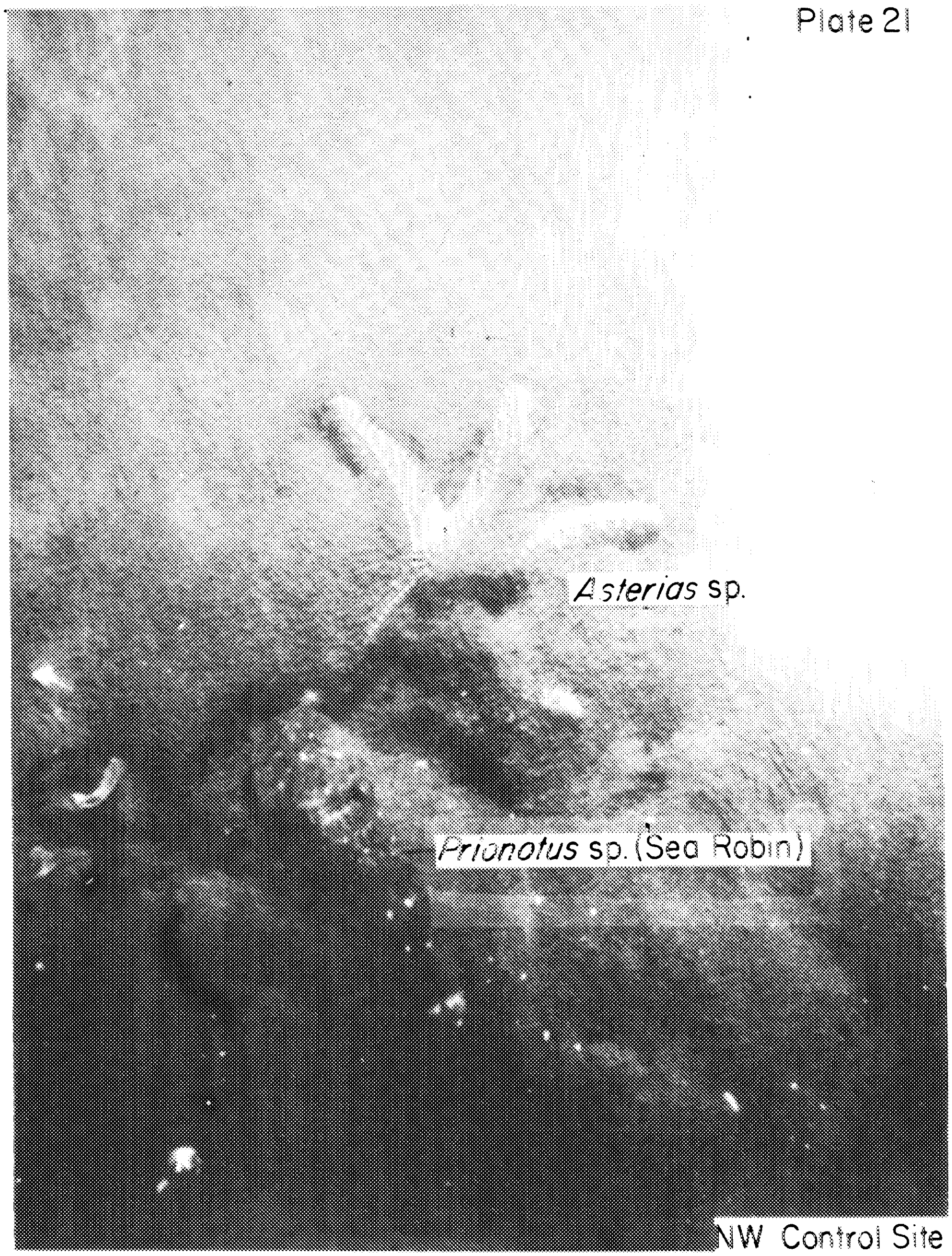
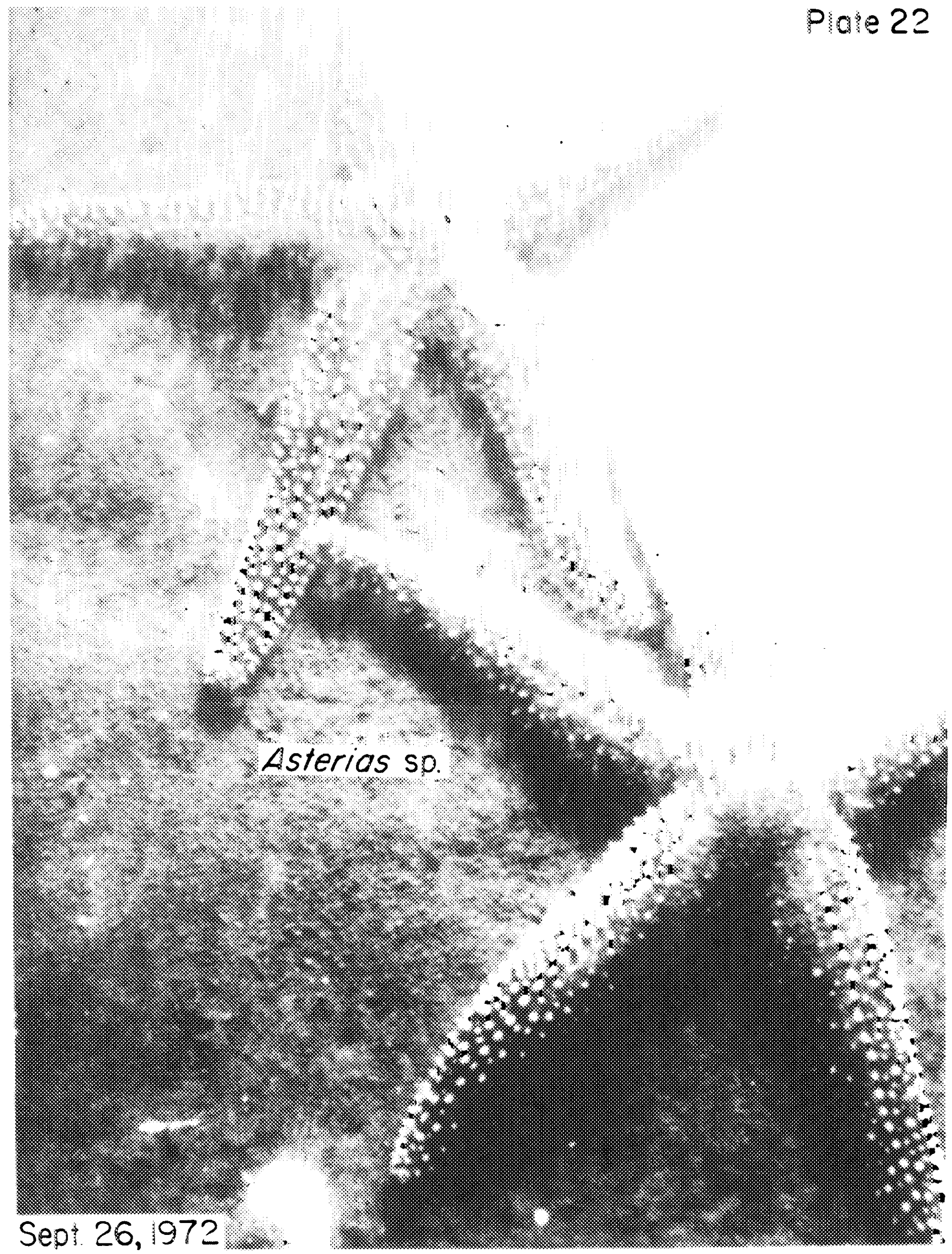


Plate 22



NW Control Site Sept. 26, 1972

Plate 23

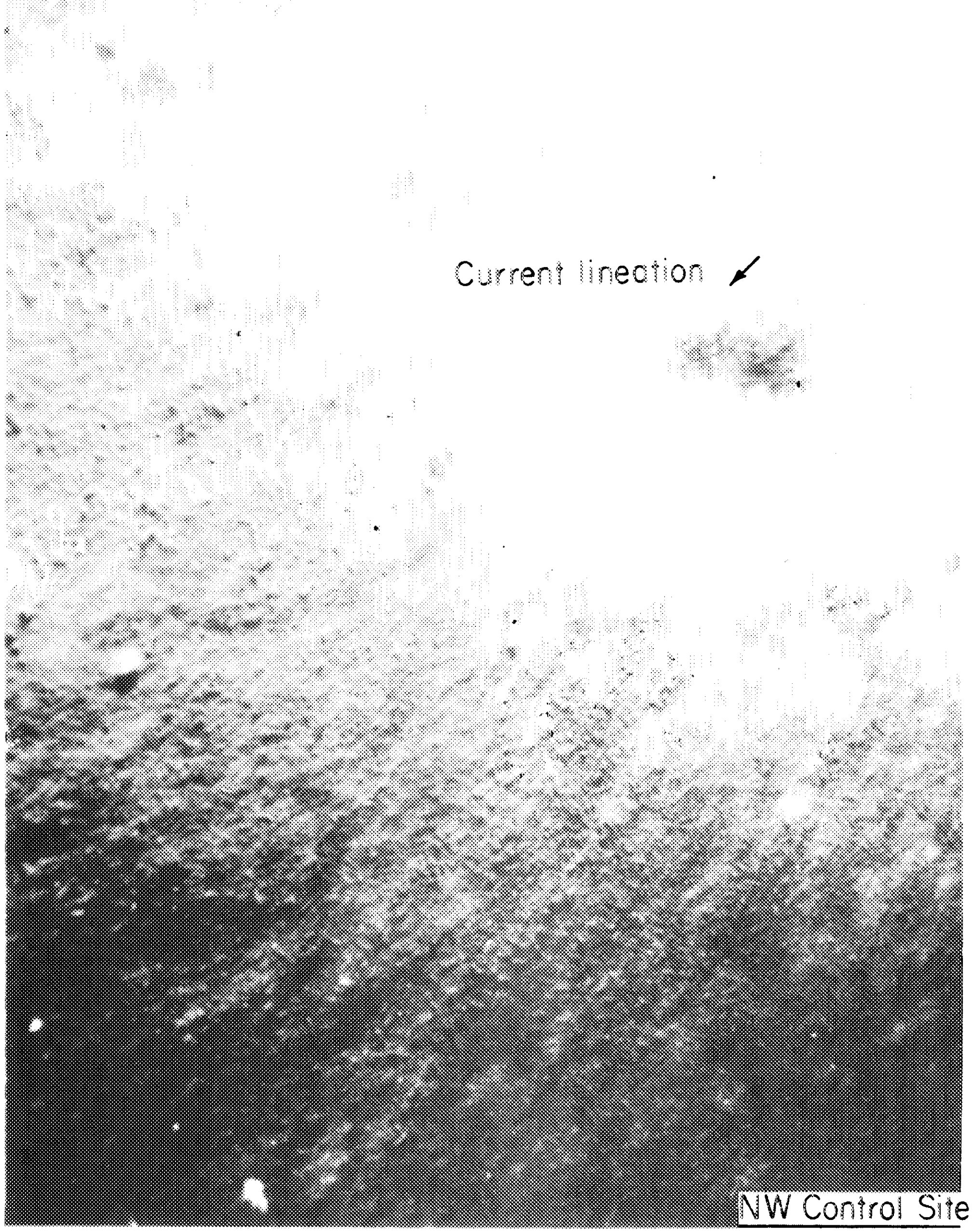
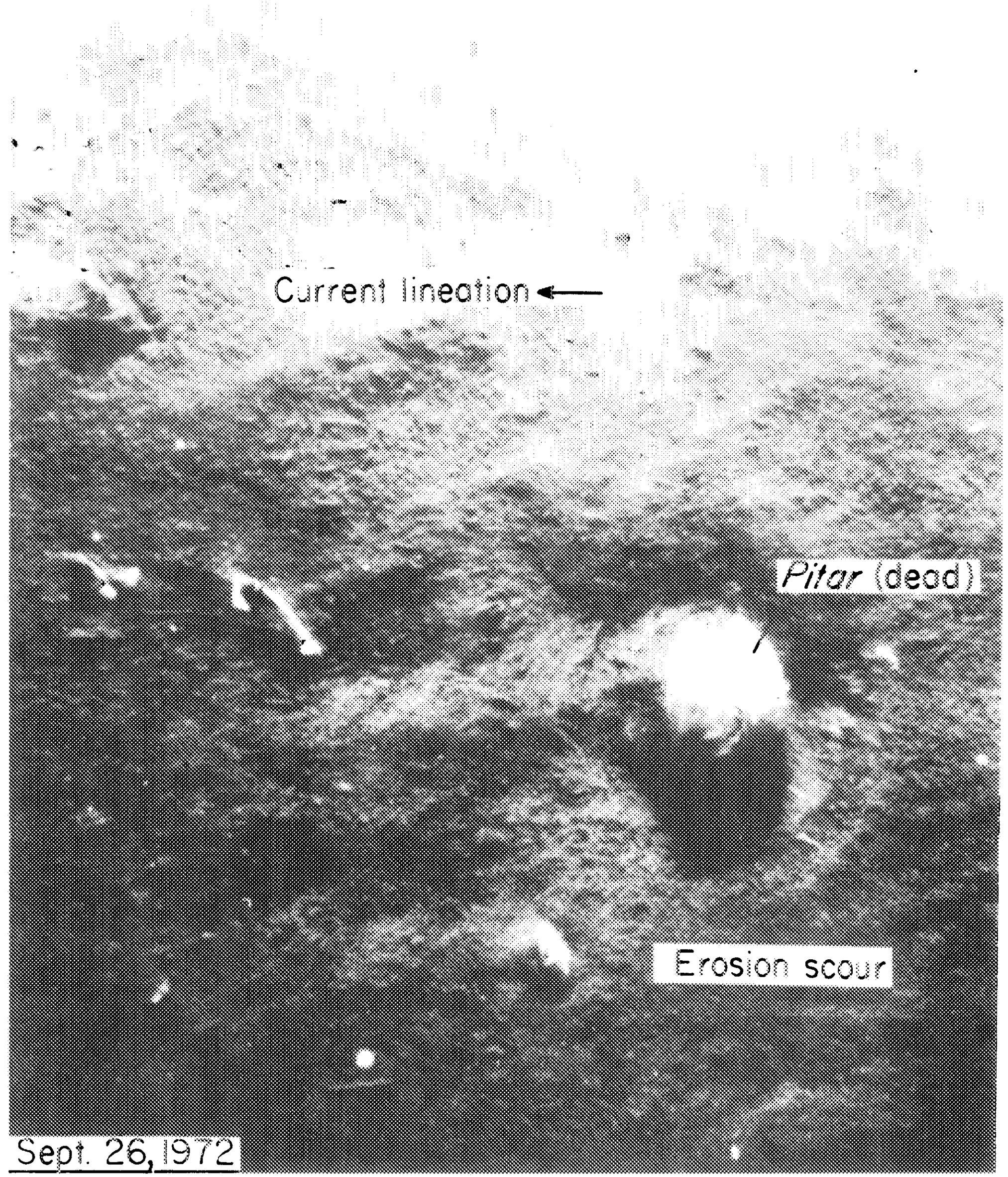


Plate 24



NW Control Site Sept. 26, 1972

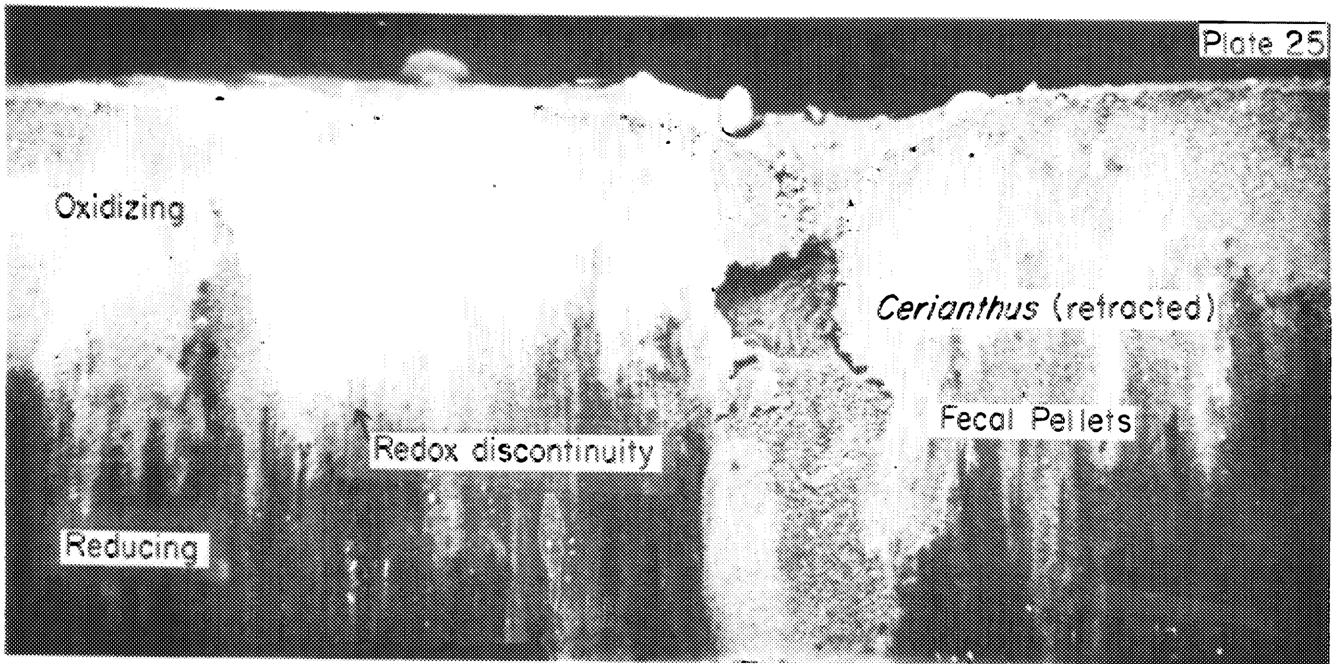


Plate 25
Oxidizing
Cerianthus (retracted)
Fecal Pellets
Redox discontinuity
Reducing

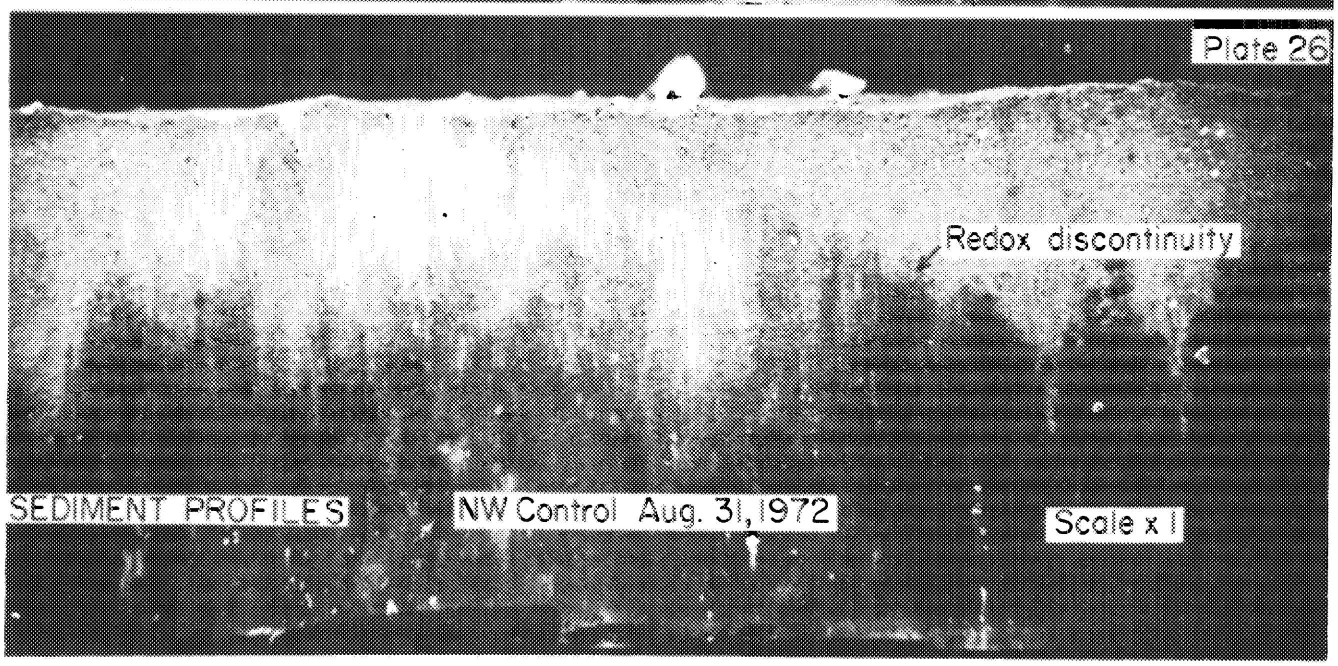


Plate 26
Redox discontinuity
SEDIMENT PROFILES
NW Control Aug. 31, 1972
Scale x I

Plate 27

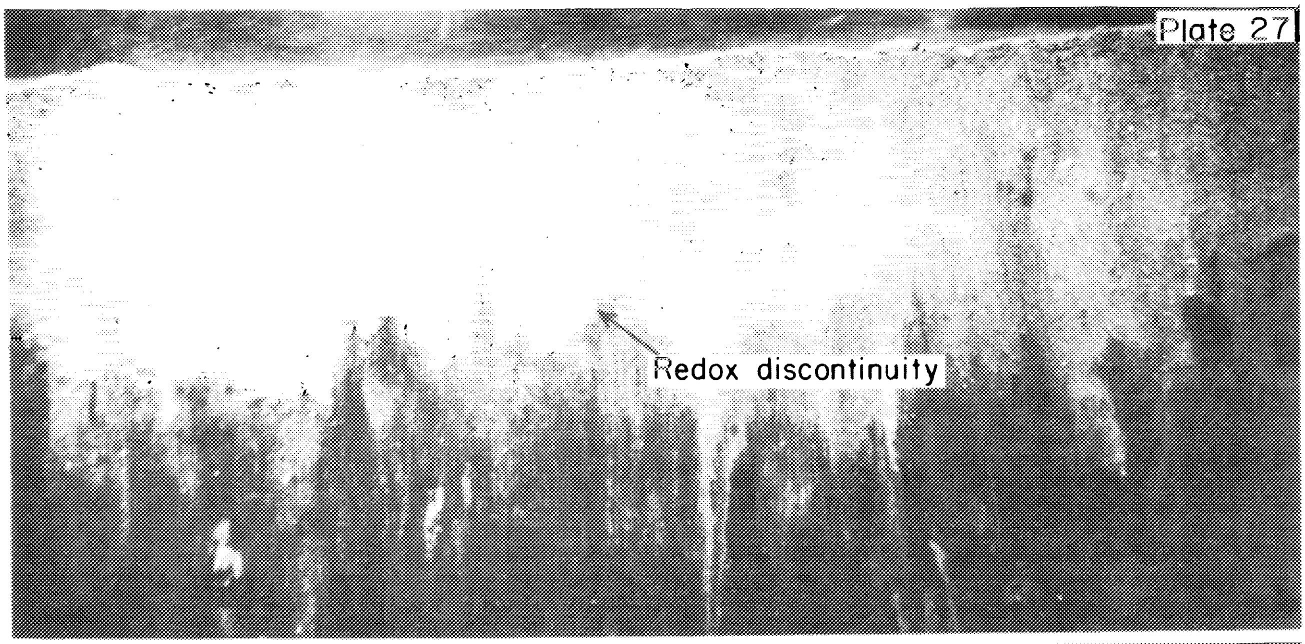


Plate 28

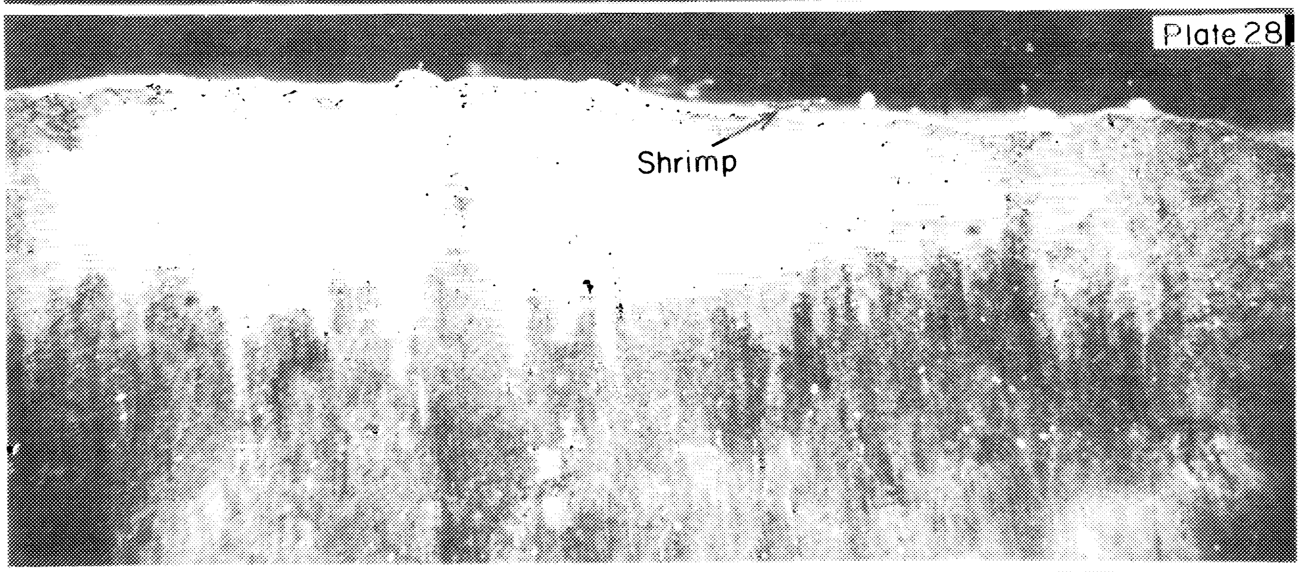
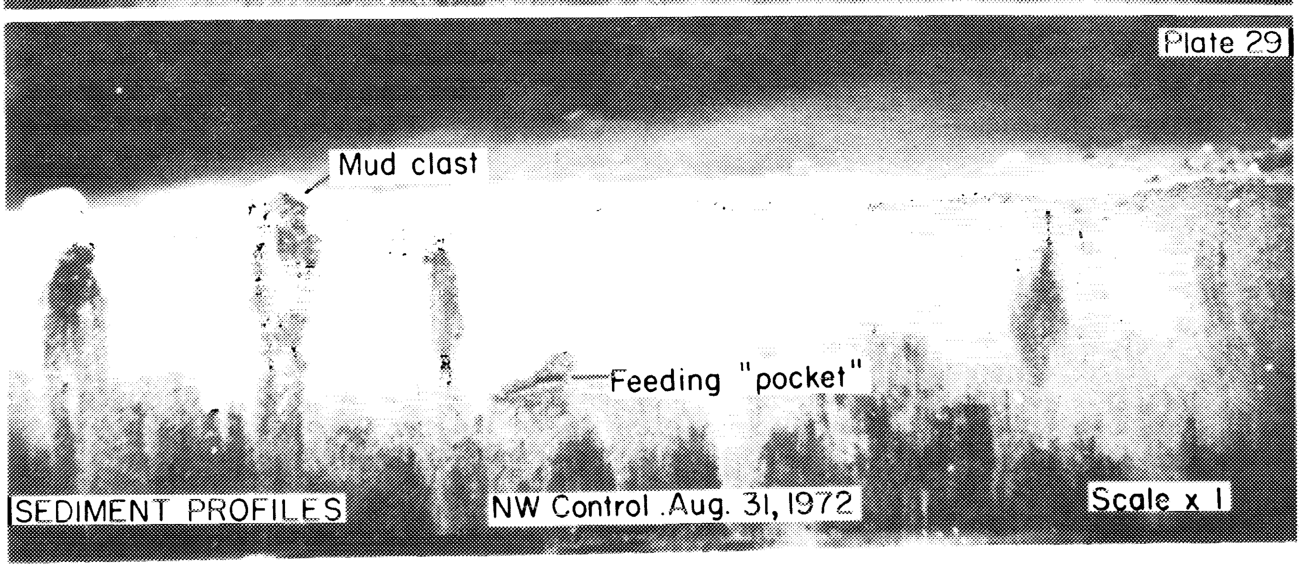


Plate 29



SEDIMENT PROFILES NW Control Aug. 31, 1972 Scale x 1

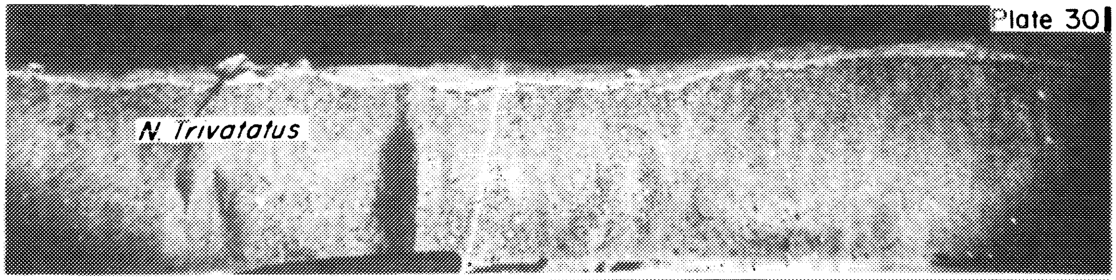
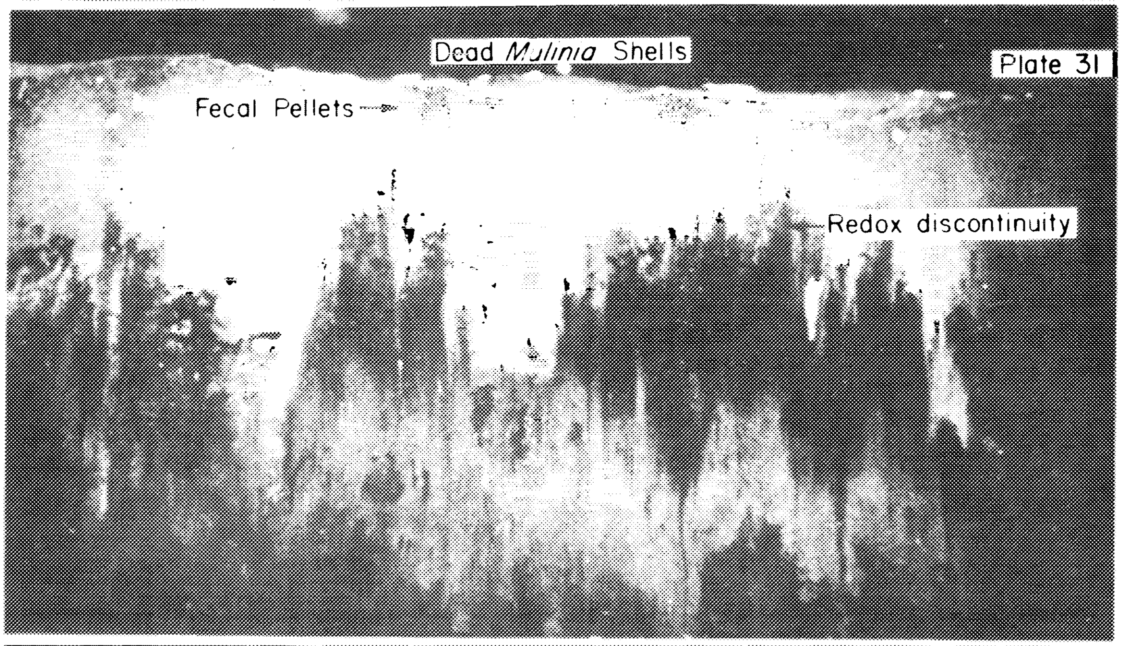
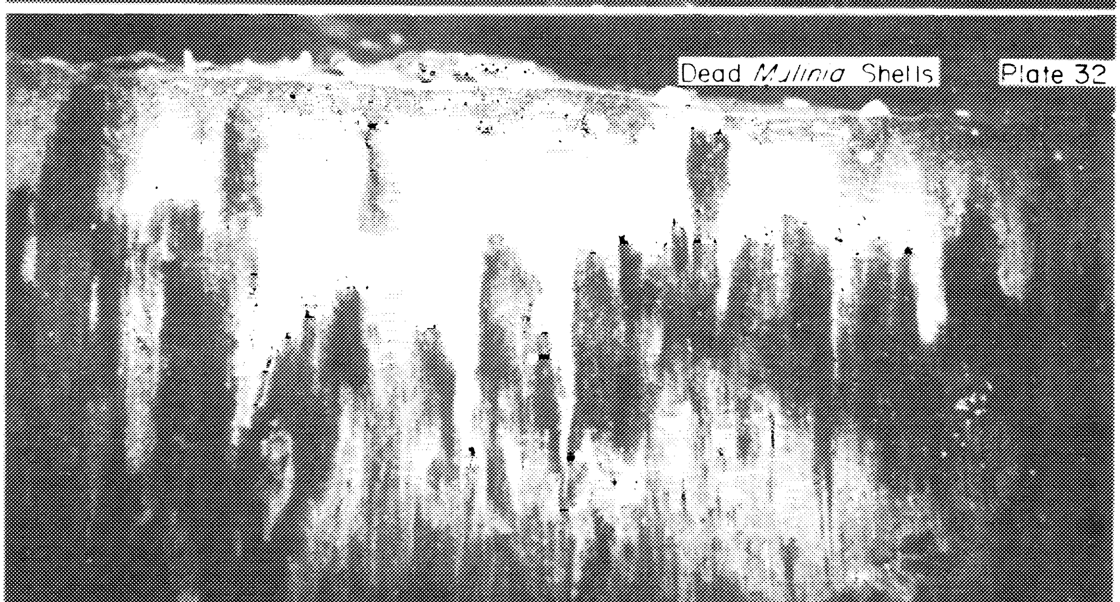


Plate 30
N. Trivatatus


Dead Mulinia Shells
Plate 31
Fecal Pellets
Redox discontinuity


Dead Mulinia Shells
Plate 32

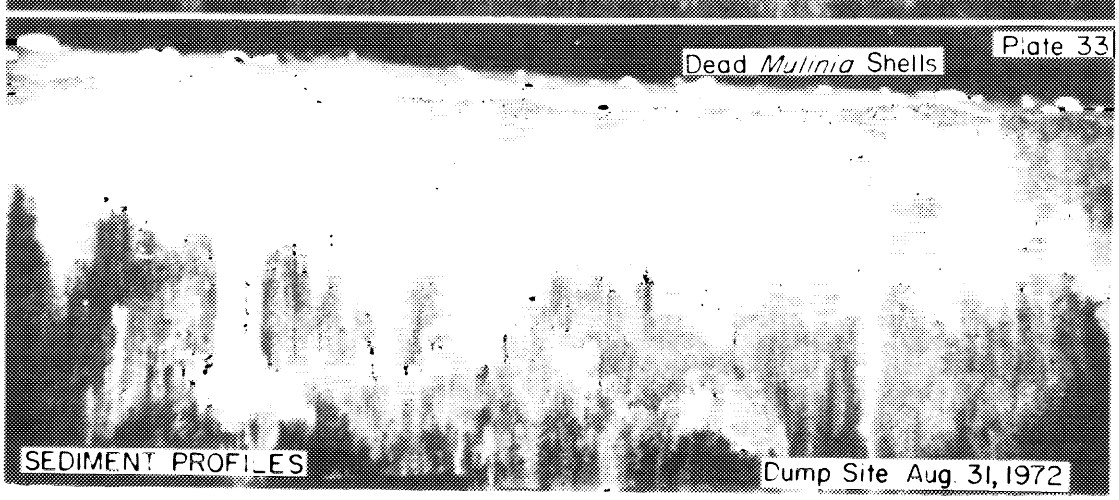


Plate 33
Dead Mulinia Shells
SEDIMENT PROFILES
Dump Site Aug. 31, 1972

APPENDIX

Numerical Data from Benthic Samples

BIOMASS BY STATION

(gm/m^2)

1	--
2	5.4
3	16.3
4	15.9
5	14.9
6	15.2
7	13.3
24	13.7
25	17.1
26	2.5
43	11.7
44	8.3
45	8.9
46	6.5
47	7.4
48a	12.0
49	15.0

Note: Station numbers are for the biological sampling stations on the dump site.

DATA SHEET USAGE PROJECT

Date Collected: July 11, 1972 Station No.: 2

Vessel: Manamet Sampler: Van Veen Dredge

Sampled Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Bivalvia		
Pitar morrhuana	88.7	.6715
Macoma tenta	88.7	.1410
Pandora gouldiana	68.1	.2690
Mulinia lateralis	54.4	.1989
Yoldia limatula	40.8	1.0433
Lyonsia hyalina	27.2	.0749
Nucula proxima	6.8	--
Gastropoda		
Retusa coniculata	13.6	.0061
Nassarius trivittatus	6.8	.0156
Polychaetes		
Streblospio benedicti	115.8	
Ampharetidae	20.4	
Melinna cristata	20.4	
Nephtys incisa	13.6	1.5456
Flabelligeridae juveniles	13.6	
Capitellidae	6.8	
Polydora ligni	6.8	
Maldanidae heads		
Crustacea		
Ampelisca abdita	54.5	
Diastylis polita	6.8	
Leptocheirus pinguis	6.8	

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Others		
Anemone	20.4	1.4676
Hydrozoa stalks		
Hemichordata	13.6	
Nemertinea	13.6	

DATA SHEET USAGE PROJECT

Date Collected: July 11, 1972 Station No.: 3

Vessel: Manamet Sampler: Van Veen Dredge

Sampled Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Bivalvia		
Mulinia lateralis	2128.	3.4048
Pitar morrhuana	299.4	2.5177
Nucula proxima	190.6	1.0535
Yoldia limatula	40.8	4.0206
Pandora gouldiana	20.4	.0688
Petricola	20.4	.0225
Lyonsia hyalina	6.8	.0143
Gastropoda		
Retusa coniculata	20.4	.0048
Nassarius trivittatus	6.8	.0218
Polychaetes		
Crustacea		
Others		
Anemone	27.2	5.2008

DATA SHEET USAGE PROJECT

Date Collected: July 11, 1972 Station No.: 4

Vessel; Manamet Sampler: Van Veen Dredge

Sampled Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Bivalvia		
Nucula proxima	619.	2.3985
Pitar morrhuana	361.	3.1918
Yoldia limatula	164.5	3.0488
Pandora gouldiana	74.9	.5680
Telina agilis	54.4	.0388
Lyonsia hyalina	20.4	.1308
Petricola	20.4	.0068
Macoma tenta	13.6	.0545
Gastropoda		
Polychaetes		
Flabelligeridae	204.3	.2523
Nemertinea	109.0	
Spionidae	95.3	
Maldanid	88.5	.6909
Owenia fusiformis	61.3	
Ampharetid	47.7	
Nephtyidae	40.9	1.4028
Pectinarid	20.4	
Capitelidae	20.4	
Maldonid X	20.4	
Paronis sp	6.8	
Terebellid	6.8	
Sigambro tentaculata	6.8	
Phyllocarid	6.8	

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Crustacea		
Ampelisca abdita	13.6	
Grapsid	13.6	
Leptocheirus pinguis	6.8	
Diastylis polita	6.8	
Pinnixia sp	6.8	
Others		
Foram	47.7	
Anemone	40.8	4.2030
Hydrozoa	20.4	
Hemichordata	6.8	
Egg	6.8	
Sipunculida	20.4	

DATA SHEET USAGE PROJECT

Date Collected: July 11, 1972 Station No.: 5

Vessel: Manamet Sampler: Van Veen Dredge

Sampled Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Bivalvia		
Mulinia lateralis	1859.	4.2583
Pitar morrhuana	599.	5.0326
Pandora gouldiana	272.1	1.5002
Lyonsia hyalina	34.1	1.3981
Yoldia limatula	27.1	.1532
Nucula	13.6	.0272
Petricola	6.8	.0041
Gastropoda		
Retusa	27.2	.0027
Nassarius	13.6	.0531
Polychaetes		
Streblospio benedicti	183.9	
Owenia fusiformis	149.8	1.0173
Polydora ligni	143.	
Pherusa affinis	74.9	
Nephtys incisa	61.3	1.3804
Ampharetidae	54.4	
Melinna cristata	47.7	
Spionidae I (B)	13.6	
Brada villosa	13.6	.0945
Terebellidae B	6.8	
Nichomache lumbricalis	6.8	
Pectinaria gouldii	6.8	

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Polychaetes (Cont.)		
Cirratulidae I	6.8	
Phyllodoce (amaitides) arenae	6.8	
Phyllodocidea I	6.8	
Capitellidae	6.8	
Crustacea		
Ampelisca abdita	95.2	
Leptocheirus pinguis	13.6	
Crangon	6.8	
Others		
Hemichordata	47.7	
Foram	13.6	
Echiurida	6.8	
Anthozoa	6.8	

DATA SHEET USAGE PROJECT

Date Collected: July 11, 1972 Station No.: 6

Vessel: Manamet Sampler: Van Veen Dredge

Sampled Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Bivalvia		
Mulinia lateralis	6020.	3.8511
Pitar morrhuana	272.1	.4420
Yoldia limulata	115.8	8.1366
Pandora gouldiana	61.3	.5434
Tellina agilis	34.1	.0654
Macoma tenta	20.4	.0654
Macoma balthica	6.8	.1437
Nucula proxima	6.8	.0347
Gastropoda		
Retusa coniculata	13.6	.0817
Nassarius trivitatus	27.2	
Polychaetes		
Nephtys incisa	74.9	1.8455
Ampharetidae A	61.3	
Owenia fusiformis	54.4	
Maldanidae	27.2	
Ampharetidae C	20.4	
Arcistrosyllis sp.	20.4	
Flabelligeridae	13.6	
Spionidae	13.6	
Ampharetidae B	6.8	
Terebellidae	6.8	
Pectinaria gouldii	6.8	

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Crustacea		
Diastylis polita	6.8	
Others		
Nemertea	27.2	

DATA SHEET USAGE PROJECT

Date Collected: July 11, 1972 Station No.: 7

Vessel: Manamet Sampler: Van Veen Dredge

Samples Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Bivalvia		
Mulinia lateralis	829.6	2.2963
Yoldia limulata	109.	6.9789
Pitar morrhuana	61.3	2.0682
Pandora gouldiana	34.1	1.1441
Tellina agilis	13.6	.0184
Macoma tenta	6.8	.0729
Lyonsia hyalina	6.8	.0368
Nucula proxima	6.8	.0027
Gastropoda		
Retusa coniculata	6.8	.0020
Polychaetes		
Nephtys incisa	54.5	.4580
Streblospio benedicti	47.7	
Sigambra tentaculata	20.4	
Melinna cristata	13.6	
Spionidae I (B)	6.8	
Polydora ligni	6.8	
Pherusa affinis	6.8	
Terebellidae A	6.8	
Ampharete sp	6.8	
Crustacea		
Unciola	6.8	

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Others		
Nemertea	40.9	.3022
Hemichordata	47.7	
Anthozoa	13.6	
Phoronis sp	6.8	

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972

Station No.: 24

Vessel: Manamet

Sampler: Van Veen Dredge

Sampled Area: .147 m^2

Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Bivalvia		
Mulinia lateralis	2770.	2.4114
Pitar morrhuana	844.	2.0376
Pandora	272.1	.5482
Yoldia limatula	122.6	4.2678
Lyonsia hyalina	20.4	.0306
Petricola	20.4	.0116
Nucula sp	13.6	.0409
Tellina agilis	6.8	.0320
Macoma tenta	6.8	.0204
Gastropoda		
Nassarius	68.1	.2397
Retusa	13.6	
Polychaetes		
Streblospio benedicti	483.5	
Polydora ligni	136.2	
Owenia fusiformis	81.7	
Melinna cristata	61.3	
Ampharetidae	54.5	
Brada villosa	54.5	
Spionidae I	47.7	
Nephtys incisa	34.1	
Sigambra tentaculata	34.1	
Nichomache lumbricalis	20.4	

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Polychaetes, (Cont.)		
Maldanidae	20.4	
Terebellidae A	20.4	
Terebellidae B	13.6	
Pectinaria gouldii	13.6	
Phyllodace I	6.8	
Phyllodace arenae	6.8	
Maldanopsia elongata	6.8	
Capitellidae	6.8	
Crustacea		
Leptocheirus pinguis	34.0	
Pinnixia sp	20.4	
Diastylis polita	13.6	
Ampelisca abdita	6.8	
Grapsid	6.8	
Others		
Anthozoa	20.4	4.1595

DATA SHEET USAGE PROJECT

Date Collected: July 25, 1972 Station No.: 25

Vessel: Manamet Sampler: Van Veen Dredge

Sampled Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Bivalvia		
Mulinia lateralis	10,438.	7.3848
Pitar morrhuana	455.6	1.7156
Pandora gouldiana	165.4	.6909
Yoldia limatula	61.2	4.9028
Petricola	20.4	.0102
Macoma tenta	20.4	.0095
Gastropoda		
Nassarius trivitatus	20.4	.1584
Polychaetes		
Streblospio benedicti	156.6	
Flabelligeridae (juveniles)	108.9	
Pherusa affinis	68.1	
Ampharetidae	54.5	
Melinna cristata	54.5	
Nephtys incisa	47.7	1.7490
Sigambra tentaculata	27.2	
Capitellidae	20.4	
Polydora ligni	13.6	
Spionidae I	13.6	
Pectinaria gouldii	13.6	
Terebellidae A	6.8	
Phyllodoce (araitides) arenae	6.8	
Cinatulidae I	6.8	

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Polychaetes (Cont.)		
Owenia fusiformis	6.8	
Nichomache lumbricalis	6.8	
Brada villosa	6.8	
Crustacea		
Ampelisca abdita	6.8	
Others		
Nemertea	--	.4816
Hemichordata	27.2	
Anthozoa	20.4	
Cumacea (Diostylis sp)	6.8	

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972

Station No.: 26

Vessel: Manamet

Sampler: Van Veen Dredge

Sampled Area: .147 m^2

Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Bivalvia		
Mulinia lateralis	1907.0	.5877
Pitar morrhuana	136.2	.3528
Nucula proxima	81.7	.0701
Pandora gouldiana	34.1	.0715
Petricola	20.4	.0054
Tellina agilis	20.4	.0034
Yoldia limatula	13.6	.3780
Macoma tenta	13.6	.0027
Lyonsia hyalina	6.8	.0034
Gastropoda		
Retusa coniculata	13.6	.0007
Polychaetes		
Nephtys incisa	40.9	.6644
Melinna cristata	27.2	
Ampharetidae	13.6	
Nimoe nigripes	6.8	
Brada villosa	6.8	
Pherusa affinis	6.8	
Streblospio benedicti	6.8	
Crustacea		
Pinnixia sp	20.4	
Ampelisca abdita	6.8	
Others		
Anemone	54.5	.4379

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972 Station No.: 43

Vessel: Manamet Sampler: Van Veen Dredge

Sampled Area: .147 m^2 Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Bivalvia		
Mulinia lateralis	2056.	1.6017
Pitar morrhuana	292.7	.6286
Pandora gouldiana	54.4	.0865
Yoldia limatula	20.4	.7505
Petricola	13.6	.0415
Tellina agilis	6.8	.0095
Gastropoda		
Retusa coniculata	34.1	.0095
Polychaetes		
Melinna cristata	108.96	.1809
Nephtys incisa	34.1	.9976
Polydora ligni	6.8	
Ampharete arctica	6.8	
Nichomache lumbricalis	6.8	
Owenia fusiformis	6.8	
Crustacea		
Pinnixia sp	6.8	
Others		
Hemichordata	13.6	
Hydrozoa stalk		
Anemone	27.2	7.4930
Nemertea	40.8	

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972 | Station No.: 44

Vessel: Manamet | Sampler: Van Veen Dredge

Sampled Area: .147 m^2 | Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Bivalvia		
Mulinia lateralis	892.	.5577
Pitar morrhuana	197.5	.5543
Petricola	20.4	.0109
Yoldia limatula	6.8	.0218
Pandora gouldiana	6.8	.0054
Nucula proxima	6.8	.0034
Gastropoda		
Retusa coniculata	13.6	
Polychaetes		
Crustacea		
Ampelisca	13.6	
Cancer	6.8	
Others		
Anemone	54.4	7.2125

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972 | Station No.: 45

Vessel: Manamet | Sampler: Van Veen Dredge

Sampled Area: .147 m^2 | Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Mulinia lateralis	5770.	1.5295
Pitar morrhuana	340.7	.5836
Pandora gouldiana	156.7	.2540
Nucula proxima	27.2	.0129
Lyonsia hyalina	20.4	.0232
Petricola	20.4	.0054
Macoma tenta	6.8	--
Gastropoda		
Retusa coniculata	54.4	.0075
Polychaetes		
Ampharetidae	88.5	
Maldanidae	68.1	
Nephtydae	47.7	1.5587
Flabelligeridae	40.9	
Spionidae	13.6	
Owenia fusiformis	13.6	
Paraonis gracilis	13.6	
Sigamtera tentaculata	6.8	
Pectinariidae (Pectinaria gouldii)	6.8	
Crustacea		
Ampelisca abdita	13.6	
Pinnixia sp	6.8	

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Others		
Anemone	81.6	4.9613
Cumacea	13.6	
Hemichordata	6.8	

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972

Station No.: 46

Vessel: Manamet

Sampler: Van Veen Dredge

Sampled Area: .147 m^2

Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Mulinia lateralis	129.4	.0701
Pandora	54.4	.1219
Pitar morrhuana	47.7	.4134
Yoldia	13.6	1.0978
Macoma tenta	6.8	.6061
Gastropoda		
Retusa	6.8	.0170
Polychaetes		
Streblospio benedicti	54.5	
Brada villosa	40.9	
Nichomache lumbricalis	40.9	
Nephtys incisa	27.2	.5216
Flabelligeridae (juvenile)	13.6	
Sigambra tentaculata	13.6	
Spionidae	13.6	
Maldanidae sp	6.8	
Polydora sp	6.8	
Crustacea		
Ampelisca abdita	68.1	
Others		
Hemichordata	61.2	.4019
Anthozoa	47.7	.1285
Phoronida	6.8	3.1912

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972

Station No.: 47

Vessel: Manamet

Sampler: Van Veen Dredge

Sampled Area: .147 m^2

Diversity Index:

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Bivalvia		
Mulinia lateralis	2452.	1.1952
Pitar morrhuana	292.7	1.0045
Pandora	115.8	.2949
Nucula sp	20.4	.0225
Yoldia limatula	6.8	1.0950
Lyonsia hyalina	6.9	.0238
Petricola	6.8	--
Gastropoda		
Retusa	88.7	.0136
Nassarius	68.1	.1158
Polychaetes		
Flabelligerid A	115.8	1.1798
Ampharetid	108.96	
Maldanid	47.7	
Nephtyid	27.2	.6406
Sigambra tentaculata	27.2	
Flabelligerid B	20.4	.5161
Streblospio benedicti	20.4	
Polydora sp	6.8	
Polynoidae	6.8	

Data Sheet Usage Project
Station No. 47, Cont.

Species List

Species	No. Individuals	Biomass, (by wt.; decalcified)
Crustacea		
Ampelisca abdita	50.8	
Grapsid	13.6	
Leptocheirus pinguis	6.8	
Diastylis polita	6.8	
Pinnixia sp	6.8	
Larval stage	6.8	
Others		
Anemone A	54.5	
Anemone B	37.5	1.3702
Hydrozoa	20.4	
Cumacea	13.6	
Nemertinea	13.6	
Hemichordata	6.8	
Sipunculid worm	6.8	.0048

DATA SHEET USAGE PROJECT

Date Collected: July 12, 1972

Station No.: 48A

Vessel: Manamet

Sampler: Van Veen Dredge

Sampled Area: .147 m^2

Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Bivalvia		
Mulinia lateralis	7470.0	2.3474
Pitar morrhuana	811.0	2.9767
Pandora gouldiana	136.2	.1934
Nucula proxima	27.2	.0743
Petricola	27.2	.0347
Tellina agilis	6.8	.0470
Yoldia limatula	6.8	.0041
Gastropoda		
Retusa coniculata	34.1	.0163
Nassarius trivitatis	6.8	.0163
Polychaetes		
Melinna cristata	61.3	
Nephtys incisa	34.1	.8486
Pherusa affinis	27.24	.1870
Ampharetidae A	13.6	
Ampharetidae B	6.8	
Maldanopis elongata	13.6	
Sigambra Aentaculata	13.6	
Brada villosa	13.6	
Nimoe nigripes	6.8	
Amphareta sp.	6.8	
Polydora ligni	6.8	
Ampharetidae C	6.8	
Pholoe minuta	6.8	
Parasnis gracilis	6.8	

Data Sheet Usage Project
Station No. 48A, Cont.

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Crustacea		
Ampelisca abdita	47.4	
Pinnixia sp.	6.8	
Others		
Nemertea	--	5.2986

DATA SHEET USAGE PROJECT.

Date Collected: July 12, 1972
Station No.: 49
Vessel: Manamet
Sampler: Van Veen Dredge
Sampled Area: .147 m^2
Diversity Index:

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Mulinia lateralis	6290.0	3.3192
Pitar morrhuana	749.0	2.1091
Pandora gouldiana	149.8	.4535
Yoldia limatula	13.6	.0123
Petricola	13.6	.0075
Gastropoda		
Retusa coniculata	68.1	.0225
Polychaetes		
Melinna cristata	54.8	
Pherusa affinis	34.	
Nephtys incisa	20.4	.8309
Polydora ligni	13.6	
Pholoe minuta	6.8	
Glycera americana	6.8	3.3116
Cossina longocinata	6.8	
Pectinaria gouldii	6.8	
Priomospio sp. (pinnata)	6.8	
Ampharetidae A	6.8	
Terebellidae	6.8	
Maldanopsis elongata	6.8	
Sigamtura tentaculata	6.8	
Crustacea		
Ampelisca abdita	54.4	--
Crangon	6.8	--
Pinnixia sp.	6.8	--

Species List

Species	No. Individuals/m^2	Biomass, (by wt.; decalcified)/m^2
Others		
Nemertinea	40.9	3.5265
Anemone	47.7	1.0676
Echiurida	6.8	.3849